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Electricity end uses, energy efficiency, and distributed energy resources baseline: *Transportation Sector Chapter*

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Any remaining errors, omissions, or mischaracterizations are the responsibility of the authors.

Scope and Organization

This report was developed by a team of analysts at Lawrence Berkeley National Laboratory, with Argonne National Laboratory contributing the transportation section, and is a DOE EPSA product and part of a series of "baseline" reports intended to inform the second installment of the Quadrennial Energy Review (QER 1.2). QER 1.2 provides a comprehensive review of the nation's electricity system and cover the current state and key trends related to the electricity system, including generation, transmission, distribution, grid operations and planning, and end use. The baseline reports provide an overview of elements of the electricity system. This report focuses on end uses, electricity consumption, electric energy efficiency, distributed energy resources (DERs) (such as demand response, distributed generation, and distributed storage), and evaluation, measurement, and verification (EM&V) methods for energy efficiency and DERs.

Chapter 1 provides context for the report and an overview of electricity consumption across all market sectors, summarizes trends for energy efficiency and DERs and their impact on electricity sales, and highlights the benefits of these resources as well as barriers to their adoption. Lastly it summarizes policies, regulations, and programs that address these barriers, highlighting crosscutting approaches, from resource standards to programs for utility customers to performance contracting.

Chapters 2 through 5 characterize end uses, electricity consumption, and energy efficiency for the residential, commercial, and industrial sectors as well as electrification of the transportation sector. Chapter 6 addresses DERs—demand response, distributed generation, and distributed storage.

Several chapters in this report include appendices with additional supporting tables, figures, and technical detail. In addition, the appendix also includes a separate section that discusses current and evolving EM&V practices for energy efficiency and DERs, approaches for conducting reliable and cost-effective evaluation, and trends likely to affect future EM&V practices.

This excerpt from the report focuses on the Transportation Sector. The table of contents included here shows the detailed scope of topics in the complete report. The full report is available at https://emp.lbl.gov/publications/electricity-end-uses-energy.

Description of Energy Models[a]

Unless otherwise noted, this report provides projections between the present-day and 2040 using the "EPSA Side Case," a scenario developed using a version of the Energy Information Administration's (EIA's) National Energy Modeling System (NEMS). Since the EPSA Side Case was needed for this and other EPSA baseline reports in advance of the completion of EIA's Annual Energy Outlook (AEO) 2016, it uses data from EIA's AEO 2015 Reference Case, the most recent AEO available at the time. However, since AEO 2015 did not include some significant policy and technology developments that occurred during 2015, the EPSA Side Case was designed to reflect these changes.

The EPSA Side Case scenario was constructed using EPSA-NEMs,[b] a version of the same integrated energy system model used by EIA. The EPSA Side Case input assumptions were based mainly on the final release of the 2015 Annual Energy Outlook (AEO 2015), with a few updates that reflect current

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[a] Staff from DOE's Office of Energy Policy and Systems Analysis authored this description.

[b] The version of the National Energy Modeling System (NEMS) used for the EPSA Side Case has been run by OnLocation, Inc., with input assumptions by EPSA. It uses a version of NEMS that differs from the one used by the U.S. Energy Information Administration (EIA).

technology cost and performance estimates, policies, and measures, including the Clean Power Plan and tax credits. The EPSA Side Case achieves the broad emissions reductions required by the Clean Power Plan. While states will ultimately decide how to comply with the Clean Power Plan, the Side Case assumes that states choose the mass-based state goal approach with new source complement and assumes national emission trading among the states, but does not model the Clean Energy Incentive Program because it is not yet finalized. The EPSA Side Case also includes the tax credit extensions for solar and wind passed in December 2015. In addition, cost and performance estimates for utility-scale solar and wind have been updated to reflect recent market trends and projections, and are consistent with what was ultimately used in AEO 2016. Carbon capture and storage (CCS) cost and performance estimates have also been updated to be consistent with the latest published information from the National Energy Technology Laboratory.

As with the AEO, the EPSA Side Case provides one possible scenario of energy sector demand, generation, and emissions from present day to 2040, and it does not include future policies that might be passed or unforeseen technological progress or breakthroughs. EPSA-NEMS also constructed an "EPSA Base Case" scenario, not referenced in this report, which is based primarily on the input assumptions of the AEO 2015 High Oil and Natural Gas Resource Case. Projected electricity demand values forecast by the EPSA Base Case and Side Case are very close to each other (within 3% by 2040). However, the values forecast by the EPSA Base Case are closer to those that were ultimately included in the AEO 2016 Reference Case.

EPSA Side Case data also are used when most-recent (2014) metrics are reported as a single year or are plotted with future projections. Doing so ensures consistency between current and forecasted metrics. Overlapping years between historical data and data modeled for forecasts are not necessarily equal. Historical data are revised periodically as EIA gathers better information over time, while forecasted cases, which report a few historical years, do not change once they are released to the public.

List of Acronyms and Abbreviations

Acronym / Abbreviation	Stands For
ACEEE	American Council for an Energy-Efficient Economy
AEO	Annual Energy Outlook
AMI	advanced metering infrastructure
AMO	DOE Advanced Manufacturing Office
ARRA	2009 American Recovery and Reinvestment Act
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BEV	Battery Electric Vehicle
CAFE	Corporate Average Fuel Economy
CAISO	California ISO
CBECS	Commercial Buildings Energy Consumption Survey
CFLs	compact fluorescent lamps
CHP	Combined Heat and Power
CO^2	carbon dioxide
CPP	Clean Power Plan
CPP	Critical Peak Pricing
CPUC	California Public Utilities Commission
CSE	cost of saved energy
CUVs	crossover utility vehicles
DCLM	Direct Control Load Management
DER	Distributed Energy Resources
DOE	U.S. Department of Energy
DSM	demand side management
DSO	Distribution System Operator
EAC	DOE's Electricity Advisory Committee
EERS	energy efficiency resource standard
EIA	U.S. Energy Information Administration
EM&V	Evaluation, Measurement, and Verification
EMCS	Energy Management Control Systems
EPA	U.S. Environmental Protection Agency
EPSA	DOE Office of Energy Policy and Systems Analysis
ERCOT	Electric Reliability Council of Texas
ESCOs	energy service companies
FCTO	DOE's Fuel Cell Technology Office
FCV	Fuel Cell Vehicle
FEMP	Federal Energy Management Program
FERC	Federal Energy Regulatory Commission
FFV	Ethanol Flex-Fuel Vehicle
FITs	feed-in tariffs
FRCC	Florida Reliability Coordinating Council
GDP	gross domestic product

Acronym / Abbreviation	Stands For
GHG	greenhouse gases
GWP	global warming potential
HEVs	hybrid electric vehicles
HOV	high-occupancy vehicle
HVAC	heating, ventilation, and air-conditioning
Hz	hertz
ICEs	internal combustion engines
ICLEI	International Council for Local Environmental Initiatives
ICT	information and communication technologies
IDM	Industrial Demand Module
IECC	International Energy Conservation Code
IEMS	Industrial Energy Management Systems
IL	Interruptible Load
INL	Idaho National Laboratory
IRP	integrated resource planning
ISO	Independent System Operator
ISO-NE	ISO-New England, Inc.
ITC	investment tax credit
kWh	kilowatt-hours
LBNL	Lawrence Berkeley National Laboratory
LCOE	levelized cost of electricity
LCR	Load as a Capacity Resource
LDV	light-duty vehicle
LED	light emitting diode
LEED	Leadership in Energy and Environmental Design
Li-ion	Lithium-ion
LMP	locational marginal pricing
LR	learning rate
LSE	load serving entity
MATS	Mercury and Air Toxics Standards
MECS	Manufacturing Energy Consumption Survey
MELs	Miscellaneous Electric Loads
MISO	Midcontinent Independent System Operator
MMWh	million megawatt-hours
MRO	Midwest Reliability Organization
MRO-MAPP	Midwest Reliability Organization-Mid-Continent Area Power Pool
MUSH	municipalities, universities, schools, and hospitals
NEMS	National Energy Modeling System
NERC	North American Electricity Reliability Council
NPCC	Northeast Power Coordinating Council
NPCC-NE	NPCC-New England

Acronym / Abbreviation	Stands For
NPCC-NY	NPCC-New York
NREL	National Renewable Energy Laboratory
NYISO	New York ISO
ORNL	Oak Ridge National Laboratory
PACE	Property Assessed Clean Energy
PC	personal computer
PCTs	programmable communicating thermostats
PEV	plug-in electric vehicle
PHEV	Plug-in Hybrid Electric Vehicle
PJM	PJM Interconnection, LLC
PTC	production tax credit
PV	photovoltaic
QER	Quadrennial Energy Review
QTR	Quadrennial Technology Review
R&D	research and development
RD&D	Research, development, and deployment
RECS	Residential Energy Consumption Survey
RETI	Real estate business trust
REV	"Reforming the Energy Vision"
RFC	Reliability First Corporation
RTO	Regional Transmission Organization
RTP	real-time pricing
SDG&E	San Diego Gas and Electric
SEIA	Solar Energy Industries Association
SERC	Southeast Electric Reliability Council
SERC-E	Southeast Electric Reliability Council -East
SERC-N	Southeast Electric Reliability Council -North
SERC-SE	Southeast Electric Reliability Council -Southeast
SGIG	Smart Grid Investment Grant
SPP	Southwest Power Pool, Inc.
SSL	solid-state lighting
TBtu	trillion British thermal units
TOU	time-of-use pricing
TRE	Texas Reliability Entity
TRE-ERCOT	TRE-Electric Reliability Council of Texas
TWh	terawatt-hours
USDA	U.S. Department of Agriculture
V2B	vehicle-to-building
V2H	vehicle-to-home
VAR	volt-ampere reactive
VOS	value of shipments
VTO	DOE's Vehicle Technologies Office

Acronym / Abbreviation	Stands For
WECC	Western Electricity Coordinating Council
WECC-CA-MX	WECC-California-Mexico Power
WECC-NWPP	WECC-Northwest Power Pool
WECC-RMRG	WECC-Rocky Mountain Reserve Group
WECC-SRSG	WECC-Southwest Reserve Sharing Group
ZEV	Zero Emission Vehicle
ZNEB	Zero-Net Energy Building

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5 Transportation Sector

In contrast to the residential, commercial, and industrial sectors of the U.S. economy, which are heavily electrified, the transportation sector currently uses virtually no electricity. In 2014, total transportation electricity consumption was about 26 trillion Btu (8 billion kWh), compared to total transportation energy consumption of about 27 quadrillion Btu.[1] In other words, electricity provides only about 0.1% of all transportation energy. Further, electricity consumption in the transportation sector represented only 0.2% of total U.S. electricity consumption in 2014.[2]

Most transportation electricity use—about 88%—is by transit, commuter, and intercity passenger rail.[3] Unless these rail modes increase usage significantly or other transportation modes become heavily electrified, electricity use for transportation will continue to play a very minor role in the U.S. electricity sector. This section will therefore focus primarily on the prospects for a major increase in transport electricity use through growth in the electrified modes and through electrification of modes now dependent on petroleum fuels. Due to the relative immaturity of markets for electric transportation technologies, projections of future consumption rates vary significantly. Therefore, this section does not attempt to project specific electricity consumption levels for transportation in the future. Rather, it is intended to provide a broad state of the industry, an overview of the major factors that may support or inhibit growth in electrified transportation, and the impacts that such growth may have on energy systems in the United States.

5.1 Key Findings and Insights

5.1.1 Current Status of Transport Electrification

Findings:

- In the U.S. transportation sector, electricity provides about 0.1% of all energy consumption; the sector remains dominated by petroleum fuels (Section 5.4).
- Most transportation electricity use—about 88%—is by transit, commuter, and intercity passenger rail. Transit rail is completely reliant on electricity, but intercity and commuter rail also rely heavily on diesel fuel (Section 5.4).

Insight: For electricity use in transportation to grow robustly, either the mode that is largely electrified—passenger rail—must grow or modes that are not currently electrified must switch from fossil fuels to electricity.

5.1.2 Predicting Future Electrification of Transportation

Findings:

- Among a fleet of about 230 million light-duty vehicles (LDVs) in 2014, about 280,000 were PEVs (Section 5.2.2).
- Competing projections of future penetration of EVs yield very different estimates, even when scenario assumptions are normalized among the projections (Section 5.8.5).

Insight: Because there are few data about why mainstream consumers may purchase PEVs, there is little basis for accurate long-term projections of future PEV sales. Models of future penetration of PEVs should be used cautiously, and preferably should be used to examine the relative impacts of different futures with different policies, degrees of technological success, oil prices, and other determining variables, rather than treating projections as robust predictors of likely PEV sales success.

5.1.3 Status of Battery Technology

Findings:

- Battery costs account for a quarter or more of total PEV costs, with variations depending on vehicle range and other factors (Section 5.3.2).
- Estimated PEV battery costs for industry leaders have been declining by about 8% per year since 2007 (Section 5.4.1).
- There is a robust battery R&D effort sponsored by both DOE and private industry, often in cooperation with the national laboratories and U.S. universities (Section 5.4.5).
- The initial high cost of PEVs is a primary barrier to their adoption (Section 5.6.1); limited utility for longer trips (unless limited range and long charging times can be overcome) is also likely to be a crucial barrier when batteries are the sole energy source, especially as the PEV market seeks to grow beyond early adopters.
- There are multiple pathways to increased battery performance and lower costs (Section 5.4.5).

Insight: It is highly likely that battery costs, and thus PEV prices, will continue to decline over time, especially if robust vehicle sales allow substantial gains in technology learning and economies of scale and a robust R&D effort continues. However, it is impossible to reliably project how low costs will go, or how much battery performance will improve. Battery performance, including rapid charging capability, must improve substantially if BEVs are to become full function vehicles.

5.1.4 Grid Impacts

Findings:

- Increased electrification of the LDV fleet will lead to both challenges and opportunities for power system operators (Section 5.5).
- Uncontrolled PEV charging can contribute to increased peak electricity demand and evening ramping requirements (Section 5.5.2).
- Controlled PEV charging can reduce costs for consumers, support grid reliability, and support the integration of variable renewable electricity generation (Section 5.5.2).

Insight: A comprehensive, modern power system that supports vehicle-to-grid communication and time-of-use pricing will be a vital component of a future where PEVs make up a large fraction of the total LDV fleet.

5.1.5 Policy Effectiveness

Findings:

- It is difficult to assess the relative effectiveness of specific policies and incentives for PEVs as technology costs and consumer perceptions are changing rapidly. Furthermore, most PEV policies are relatively young (Section 5.7).
- Policies to reduce the high up-front cost of PEVs and provide institutional support can promote early market growth (Section 5.7).

Insight: It is likely that PEV adoption can be most effectively supported through a combination of direct financial incentives, regulations and mandates, consumer awareness campaigns, and institutional support.

5.2 Characterization

5.2.1 Ultra-Light-Duty Vehicles

Motorcycles are generally defined as two- (or three-) wheeled vehicles powered by a motor and capable of carrying one or two riders. As of 2014, there are approximately 8.4 million registered motorcycles in the United States.[4] Although motorcycles are often characterized as fairly powerful vehicles, less powerful motor scooters and "motor bikes" also belong to this category. For example, motor scooters are a subgroup of motorcycles with a step-through frame and a platform for the feet. Motorcycles with engines less than 50 cc do not have to be registered but often can operate on the street. Motorized bicycles are also in this category and are generally not required to register, so motorcycle sales figures based on registration exclude these bikes.

There are already several manufacturers of electric motorcycles, including scooters, but U.S. sales currently number only a few thousand. Electric-motor assist bicycles[a] are also becoming quite numerous, though sales estimates vary. One industry estimate placed 2014 sales in the United States as high as 276,000[5] and another estimated 2013 sales at 173,000.[6]

5.2.2 Light-Duty Vehicles (LDVs)

Table 5.1. Breakdown of 2014 Vehicle Stock (in Thousands) [7]

Vehicle Type	Cars	Trucks
Conventional Internal Combustion Engine (ICE)	122,720	86,170
Ethanol Flex-Fuel ICE	2,970	10,390
Hybrid Electric	2,800	420
Plug-in Hybrid Electric	180	0
Battery Electric	84	14
Other	170	690
Total	**128,910**	**97,690**

The large majority (92%) of existing cars and trucks are conventional vehicles that are powered entirely by conventional fossil fuels (some with up to 10% ethanol). Only a very small minority (0.1%) are plug-in electric vehicles (PEVs) powered by electricity from the grid.

There currently are more than 200 million LDVs—passenger cars, minivans, crossover and sport utility vehicles (CUVs, SUVs), and pickup trucks—registered in the United States. However, definitional issues make precise numbers difficult to determine. According to EPSA Side Case (and in AEO 2015), there were 129 million passenger cars and 98 million light trucks in 2014,[8] while the Transportation Energy Data Book estimated 114 million passenger cars in 2013 and 120 million two-axle, four-tire trucks in that year.[9] The large majority of these (95% of cars and 88% of trucks) are conventional vehicles that rely entirely on internal combustion engines (ICEs) that are powered by gasoline or diesel fuels. Most of the "alternative-fuel vehicles" either are capable of using ethanol (although most of these are fueled primarily with gasoline) or are hybrid electric vehicles (HEVs), which use primarily conventional fuels and do not draw electricity from the grid. Only a small number of cars, approximately 264,000 in 2014, are

[a] Also known as *e-bikes,* these generally allow propulsion via pedaling, pedaling plus motor assist, or motor alone.

PEVs—either BEVs or plug-in hybrid electric vehicles (PHEVs). Even fewer (approximately 14,000) trucks are PEVs. Table 5.1 displays these values.

According to EIA, LDVs consumed nearly 15 quadrillion Btu of energy in 2014, 56% of all energy consumed by transportation. Electricity accounted for a small fraction (3 trillion Btu) of that energy—roughly 0.02%.[10] There are several classifications of LDVs that utilize electricity in some form, as outlined in Table 5.2. A number following the classification (e.g., PHEV10) typically refers to the maximum electric-powered range in miles. For LDVs, the drivetrain options include pure battery electrics (electricity provides all motive power) and plug-in hybrids, where both fuel-powered engines and electric motors provide direct or indirect motive power.

Among PEVs, PHEVs that use both an engine and motor to drive the wheels have the smallest batteries—5 to 10 kWh of storage for existing models—and therefore the shortest electric range. For example, the 2015 Toyota Prius PHEV has an electric range of less than 10 miles.[a] Some PHEVs have battery capacities of about 10 to 20 kWh with electric ranges currently up to 75 miles and total (electric plus fuel-driven) ranges over 300 miles—for example, the 2016 Chevrolet Volt (53-mile electric range, 380-mile total range). These longer electric range PHEVs use only the motor to drive the wheels in most situations, with their ICEs used primarily as generators. Pure BEVs contain no ICE, and most have batteries larger than 20 kWh with EPA-rated electric ranges from 80 to as high as 265 miles according to fueleconomy.gov. The Tesla Model S has an EPA-rated range of 208 miles with a 65 kWh battery, or 265 miles with an 85 kWh battery. However, mass-market BEVs generally have ranges closer to 100 miles. For example, the 2016 Nissan LEAF has an EPA-rated range of 107 miles with a 30 kWh battery pack.[11] These ranges reflect the current state of technology; as batteries continue to improve, greater capacities and longer ranges will be achieved. This report refers to any vehicle that can be plugged in and charged by an external source as a PEV.

Despite their ability to run on gasoline, PHEVs may still electrify a very high percentage of miles driven. Idaho National Laboratory (INL) has shown that Chevrolet Volt drivers (2014 electric range of 38 miles) electrified 75% of their miles by recharging frequently (at home and, when available, at work or at public chargers).[b] [12] The 2016 Volt has a longer range (53 miles), which should increase the fraction of electrified miles. On the other hand, shorter-range PHEVs will electrify a smaller percentage of miles driven (the Ford C-Max Energi has 20 miles of electric range, and the 2015 Toyota Prius PHEV has 11 miles).[13]

However, the combination of a higher availability of public chargers in the future and the relatively short distances that most drivers travel most days may allow PHEVs to electrify a relatively large percentage of their miles even when their electric ranges are relatively short. The 2009 National Household Travel Survey showed that the average daily travel of rural and urban cars surveyed was 34.18 miles and 23.14 miles, respectively.[14] The Alternative Fuels Data Center estimates that a PHEV with 14 miles of electric range can electrify 50% of miles driven by the average driver with a daily recharge, based on data from the 2001 National Household Travel Survey.[15]

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[a] The EPA–rated range is 6 miles. This model has been discontinued, and the next version is expected to have a much longer electric range, with speculation about range varying from 15 miles up to about 30 miles.

[b] Because many of these drivers were “innovators” and “early adopters,” it is not clear that mainstream purchasers would electrify the same percentage of their miles driven.

Table 5.2. Primary Electric Classifications That Appear in This Report

Vehicle Type	Description	Example
Conventional Vehicle	Contains only an internal combustion engine (ICE) that is powered by gasoline or other fossil fuels.	
Fuel Cell Vehicle (FCV)	Uses the chemical reaction between hydrogen and oxygen to create electricity to power an electric motor.	Toyota Mirai, Hyundai Tucson
Ethanol Flex-Fuel Vehicle (FFV)	Contains an internal combustion engine that is powered by gasoline, ethanol (E85), or a mixture of the two.	Ford Focus FFV, Dodge Dart FFV
Hybrid Electric Vehicle (HEV)	Contains a battery and electric motor(s) as well as an internal combustion engine. The battery may be charged by the engine or through regenerative breaking to increase fuel efficiency but cannot be charged by an external source, i.e., HEVs use no grid electricity.	Honda Accord Hybrid, Toyota Prius
Plug-in Hybrid Electric Vehicle (PHEV)	Similar to an HEV, contains a battery, electric motor(s), and an internal combustion engine. The key distinction is that a PHEV has a larger battery and motor than an HEV and an electric range (currently) between 10 and 75 miles per charge and can also be charged by an external source. Typically, the combined electric and ICE range is over 300 miles. Some sources refer to PHEVs as only that group of plug-in hybrids that use both motors and ICE engines to drive the wheels, and which generally have short electric ranges of between 10–20 miles. In that nomenclature, vehicles that have longer electric ranges and use only the motor to drive the wheels in most driving situations are called Extended Range Electric Vehicles, or EREVs. This report uses the term PHEV for all plug-in hybrids.	Toyota Prius PHEV, Chevrolet Volt
Battery Electric Vehicle (BEV)	Does not contain an ICE; all power is provided by a battery that must be charged by an external source. Current BEVs have a U.S. Environmental Protection Agency (EPA) rated all-electric range between 50 and 265 miles.	Nissan LEAF, Tesla Model S
Plug-in Electric Vehicle (PEV)	Any vehicle that can be charged by an external source or through a plug. This umbrella term includes both PHEVs and BEVs.	

A potential long-term roadblock to PHEVs is the cost of their dual drivetrains; some estimates project PHEV costs to remain significantly more expensive than ICE drivetrains even with projected battery cost reductions.[16] If this barrier could be overcome, prospects for significant increased market shares of these vehicles would improve considerably.

Although electric cars were introduced to the United States in 1890, and for a time afterwards electric cars were strong competitors to gasoline-fueled cars, the 2010 introduction of the Nissan LEAF (a BEV) and Chevrolet Volt (a PHEV) represented a new start for mass-market EVs. There are currently about 25 plug-in electric models available and, as of 2014, LDV stock of roughly 280,000 PEVs in the United States.[17] Virtually all of these vehicles are passenger cars, with CUV models recently introduced and no mass-produced electric passenger vans available. Some additional automakers are planning to introduce mass-market BEVs with a 200-mile range in the near future. For example, Chevrolet has stated it will introduce a 200-mile range crossover, the Bolt, in 2016 (as a 2017 model year vehicle). Appendix Table 7.9 lists the mass-market PEVs that are currently available for purchase, along with their fuel efficiencies.

5.2.3 Medium- and Heavy-Duty Vehicles

Freight trucks (greater than 10,000 pounds) are by far the largest freight carrier in the United States in terms of total tons carried. Freight trucks and rail are approximately equal in terms of ton-miles carried—1,247 billion ton-miles for trucks versus 1,212 billion for rail.[18] According to the 2012 Commodity Flow Survey, for freight carried by a single mode, trucks carried 8,060 million tons compared to rail's second-place 1,629 million tons.[19] Multimodal flows were much smaller, with combined truck and rail carrying only 213 million tons.[20] However, rail tends to dominate in transport of raw materials (especially coal), which often is shipped very long distances.

Freight trucks drove 268 billion vehicle miles in 2013, about 10% of LDV miles, but consumed 5.51 quads of energy, more than 33% as much energy as LDVs.[21] The largest of these trucks—Class 7 and 8 combination trucks (trucks with trailers)—account for about 2.4 million vehicles and 168 billion vehicle miles in 2013.[22] This large increase from 905,000 vehicles and 35 billion vehicle miles traveled (VMT) in 1970[23] was likely largely driven by economic growth. This class of trucks was also responsible for two-thirds of total freight truck energy use, with all single-unit (Class 3 through 8) trucks consuming the rest.[24]

Class 7 and 8 combination trucks drove an average of about 75,000 miles each in 2014, or about 250 miles per day assuming 300 driving days per year. Electrifying these trucks with current or readily foreseeable battery technology would be impossible without a massive network of fast chargers and willingness to stretch delivery schedules to allow several charging stops per day. However, for shorter-haul trucks, it may be possible to use a version of PHEV technology with diesel generators to electrify some of a truck's miles. FedEx has reportedly tested such a system.[25]

The only type of electrification that is being actively pursued for long-distance heavy trucks is for idle reduction. Drivers of long-haul trucks often idle their engines during rest stops or while waiting for delivery, with total idling losses estimated as high as 5% of total freight truck energy consumption.[26] One option to reduce idling is electrification of truck heating and cooling equipment combined with plug-in equipment at rest stops, or special equipment at rest stops that provide heating and cooling (as well as entertainment) services. Other options include a variety of onboard devices (e.g., auxiliary power units) that burn fuel, but at a much lower rate than the truck's engine.

Smaller trucks for freight hauling—delivery vans and smaller single-unit trucks (class 2 light-duty trucks, gross vehicle weight 6,001 to 10,000 lb., and classes 3 through 6 medium-duty trucks, gross vehicle weight 10,001 to 26,000 lb.)[a]—may be targets for electrification. Shifts in retail sales toward the Internet require considerable changes in goods delivery. Online retailers like Amazon are establishing multiple

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[a] Typical vehicles are: Class 2, Ford F-250 pickup; Class 3, Ford F-350; Class 4, Dodge Ram 4500; Class 5, GMC 5500; and Class 6, Ford F-650.

distribution centers that ship goods fairly short distances. FedEx and UPS, as well as the U.S. Postal Service, have tested plug-in delivery vehicles (as well as hybrid electric and natural gas vehicles). Data on VMT and energy use for vehicles in these size classes are not readily available. Table 5.3 shows vehicle sales for smaller trucks. There currently is essentially zero penetration of electrified heavy-duty vehicles.

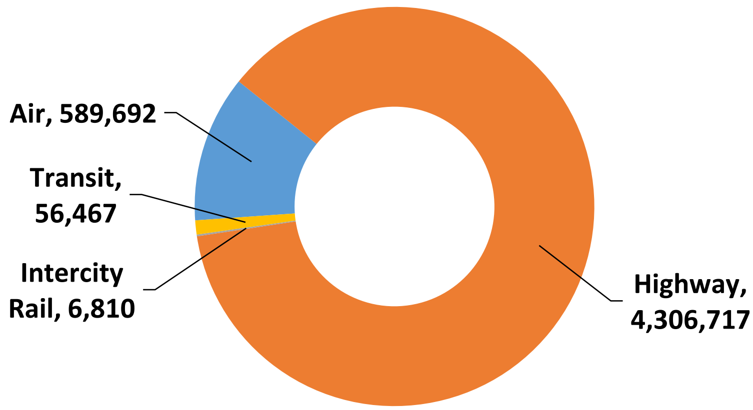
Table 5.3. New Retail Truck Sales by Gross Vehicle Weight, 2000–2014 (in Thousands)[27]

Calendar Year	Class 2 6,001– 10,000 lb.	Class 3 10,001– 14,000 lb.	Class 4 14,001– 16,000 lb.	Class 5 16,001– 19,500 lb.	Class 6 19,501– 26,000 lb.	Class 7 26,001– 33,000 lb.	Class 8 ≥ 33,001 lb.	Total
2000	2,421	117	47	29	51	123	212	8,965
2001	2,525	102	52	24	42	92	140	9,050
2002	2,565	80	38	24	45	69	146	9,035
2003	2,671	91	40	29	51	67	142	9,357
2004	2,796	107	47	36	70	75	203	9,793
2005	2,528	167	49	46	60	89	253	9,777
2006	2,438	150	50	49	70	91	284	9,268
2007	2,623	166	51	45	54	70	151	8,842
2008	1,888	135	36	40	39	49	133	6,680
2009	1,306	112	20	24	22	39	95	5,145
2010	1,513	161	12	31	29	38	107	6,137
2011	1,735	195	10	42	41	41	171	6,951
2012	1,811	223	9	55	40	47	195	7,544
2013	2,077	254	12	60	47	48	185	8,298
2014	2,275	264	13	67	52	54	220	9,154

5.2.4 Public Transit

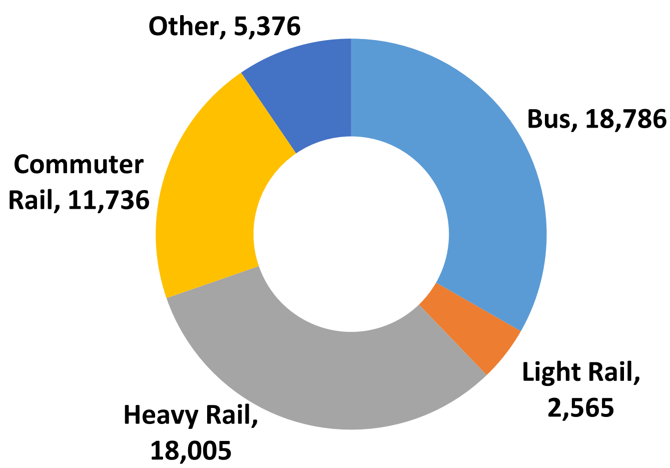
All public transit modes together provided 56.5 billion passenger miles (p-mi) in 2013, which is 1.1% of U.S. passenger travel in that year (Figure 5.1).[28] The preponderance of transit service came from heavy rail systems (18 billion p-mi), commuter rail (12 billion p-mi), and buses (19 billion p-mi); light rail systems (2.6 billion p-m) and trolley buses (0.2 billion p-mi) played minor roles (Figure 5.2).[29] Table 5.4 shows the multiple power sources of the U.S. transit system as of January 2014. Electricity is virtually the sole power source for light and heavy rail transit and trolleybus. Commuter rail systems with self-propelled cars are also essentially fully electric, but many commuter rail systems use traditional locomotives pulling unpowered cars. Aside from trolleybuses, which are dominantly electric but use some diesel for off-wire operation, non-rail transit (primarily bus systems) is powered by gasoline, diesel, and natural gas, with electricity providing only 0.1% of total energy.

Figure 5.1. U.S. passenger miles by mode in 2013 (in millions)[30]



Highway travel accounts for the majority (87%) of passenger miles traveled in the United States, with air travel accounting for most of the remainder.

Figure 5.2. Breakdown of U.S. transit passenger miles (p-mi) for 2013 (in millions)[31]



Overall, rail travel accounts for 32,306 million of the 56,467 million p-mi traveled for transit, or 57% of the total.

Table 5.4. Vehicle Power Sources by Mode of Transportation, Public Transit Only, as of January 2014[32]

Public Transportation Mode	Electricity	Diesel or Gasoline	Hybrid	Other
Bus	0.1%	57.2%	17.5%	25.1%
Commuter Bus		97.8%		2.2%
Commuter Rail (Self-Propelled Cars)	96.5%	3.5%		
Commuter Rail (Locomotives)	4.1%	95.9%		
Demand Responsive Transit		82.4%	1.9%	15.6%
Ferryboat		60.5%	39.5%	
Heavy Rail	100.0%			
Hybrid Rail		100.0%		
Light Rail	100.0%			
Other Rail	46.7%			53.3%
Streetcar	100.0%			
Transit Vanpool	0.5%	83.0%		16.6%
Trolleybus	94.2%			5.8%

Demand Responsive Transit is defined as "roadway service directly from an origin to a destination determined by the rider and not following a fixed-route."

Buses

There are approximately 72,000 transit buses in service in the United States (not including intercity and shuttle buses), virtually all of them fueled by gasoline, diesel, and natural gas.[33] In 2013, motor buses provided nearly 19 billion p-m of service.[34] Total transit bus energy use in 2014 was 107 trillion Btu, about 0.4% of total transportation energy use.[35]

Electric transit buses can either use overhead wires (trolleybuses) or onboard batteries for power. Trolleybuses are in common use in San Francisco but not elsewhere in the United States, and it seems unlikely that this will change. Battery electric buses are relatively new in the United States, with most serving as shuttle buses in airports. Some transit agencies use them in regular service—e.g., Foothill Transit in suburban Los Angeles. However, with current battery technology, most have short ranges—as low as 30 miles—that require frequent recharges. Some recent models by BYD and Proterra have ranges of 150 miles or more.[36] These buses offer the potential for electric buses to satisfy daily urban service without long pauses for charging, or even rural service with perhaps one charging event during service hours.

Another bus option, recently in service in China, uses ultracapacitors for power. These can store only modest amounts of electricity but can be recharged in a few minutes. The buses recharge at station stops every few miles by inserting a probe into an outlet. An alternative option, not yet introduced, is a bus with batteries plus ultracapacitors, enabling rapid recharging at stations to increase range.

Purchase costs for buses vary widely because of differences in size, features (including wheelchair and handicapped accessibility), and performance. Thus, data for identical buses are not readily available. Typical diesel-powered buses for transit service cost roughly $450,000; hybrid buses cost at least $100,000 more, and electric buses cost nearly twice as much.[37] Transit services contemplating the use of electric buses must account for charging station costs and scheduling issues associated with required charging times. Buses with greater electric range now becoming available will greatly reduce or eliminate this latter issue for most urban transit routes, as they could operate all day on a single charge and therefore would only be charged overnight. Also, electric buses will save large amounts on fuel and potentially on maintenance costs as well.

Rail

Transit rail systems, including both heavy and light rail, are virtually solely electrically powered. These systems are typically bidirectional at all times and operate primarily within urban centers, e.g., the Metro in Washington, D.C. There are 15 heavy rail systems in the United States, 5 hybrid rail systems, and 24 light rail systems.[a] [38] Heavy rail systems had 10,389 rail cars and nearly 2,300 miles of track in 2013, hybrid systems had 59 cars, and light rail systems had 2,054 cars and about 1,500 miles of track.[39] In 2013, transit rail consumed 16 trillion Btu of electric energy.[b] [40]

Commuter rail systems in 2013 included about 7,300 rail cars and 8,400 track miles.[41] Commuter rail systems use both electric and diesel locomotives. In contrast to transit rail, commuter rail systems tend to be heavily unidirectional, designed to serve suburban commuters heading into and out of the urban core, e.g., the MARC train that services Maryland and Washington, D.C. Commuter rail energy use in 2013 was 6.2 trillion Btu of electricity and 12.9 trillion Btu of diesel fuel.[42] In 2013, intercity rail service provided 6.8 billion p-mi of service, a little more than 0.1% of total U.S. p-mi traveled.[43] As opposed to transit and commuter rail systems, which typically serve a single metropolitan area, intercity rail systems provide service between major cities, e.g., the Amtrak or Acela trains with service between Washington, D.C., and New York City. Most intercity rail uses diesel locomotives. In 2014, electricity provided only 1.93 trillion Btu out of a total 19.29 trillion Btu of energy consumed by the intercity rail system, or roughly 10% (the electrified share of p-mi was higher, given the greater efficiency of that service).[44]

5.2.5 Freight Rail

Class I freight railroads consumed 466 trillion Btu in 2014, about 2% of total transportation energy use.[45] Essentially all of that energy was attributed to diesel locomotives, most with diesel-electric hybrid powertrains. Class I freight railroads operated 25,000 locomotives and 374,000 freight cars in 2013.[46] This represents a large shift away from rail and toward trucks over the past several decades, as there were 1,424,000 freight cars in operation in 1970—signaling a drop in freight car ownership of 74% during this period.[47]

Although several freight lines conducted studies of rail electrification in the 1980s and 1990s, a number of factors have stifled industry interest in electrification, including:[48]

- High capital costs of electrification and required system upgrades
- The need to replace signal systems
- Private ownership of freight rail systems
- Resulting limited density of freight operations on multiple routes
- Incompatibility of electric locomotives on non-electrified segments of track
- Moderated diesel fuel prices

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[a] Systems that combine diesel electric powertrains with a battery, allowing them to recapture braking energy.

[b] Assuming 3412 Btu/kWh; note that the total primary energy used to produce this electricity is larger by about a factor of 3 due to conversion and distribution losses.

However, rail electrification has several advantages, including more powerful locomotives, reduced maintenance of locomotives, and greatly reduced energy costs. Although private freight rail lines appear unlikely to electrify on their own, some combination of public incentives and requirements might stimulate electrification.

5.2.6 Charging Infrastructure

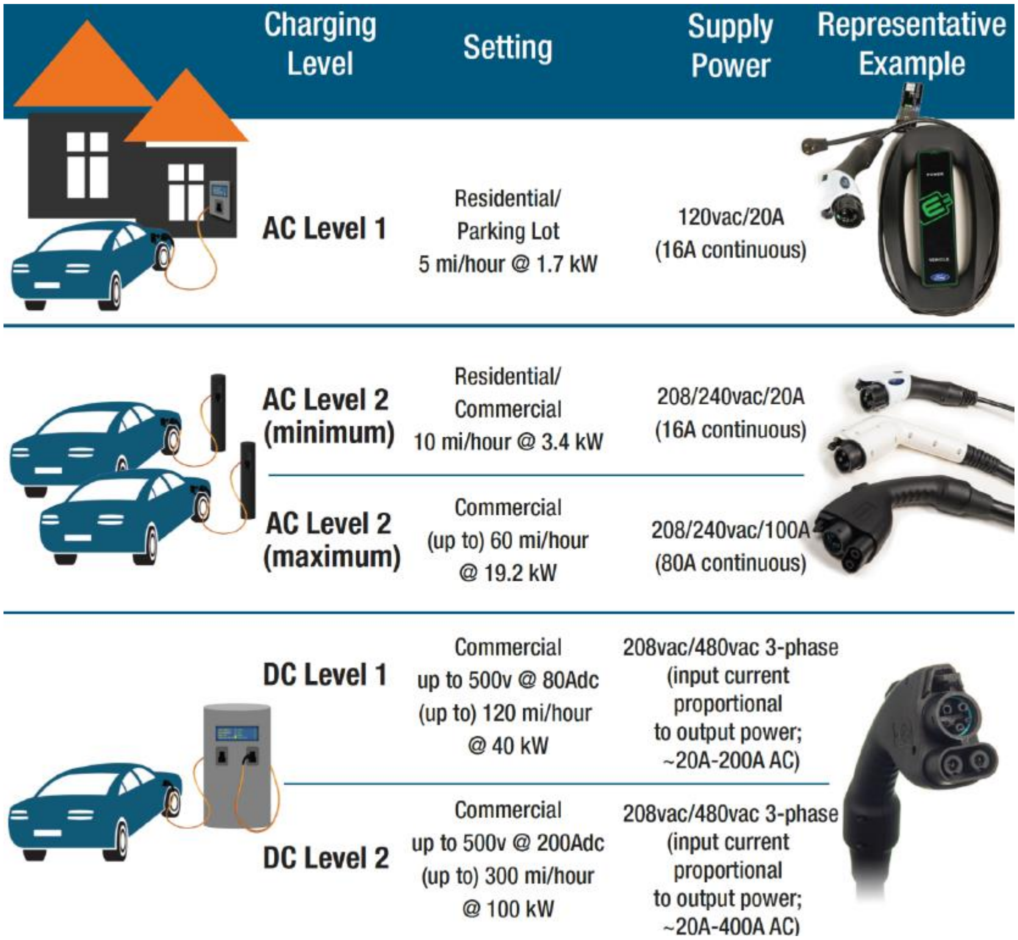
BEVs can use two types of charging infrastructure: (1) chargers for long-term charging at homes, in residential parking garages, or depots for buses and other vehicles and (2) public or workplace chargers that allow such vehicles to gain extra range when away from their home charger. Public chargers are open to all users while private chargers are limited to select vehicles. The relative importance and utilization of these resources will depend on the characteristics of individual PEV owners. For example, some households may use a BEV primarily for short trips to and from their home, while maintaining a separate vehicle for longer range travel. In this case the availability of pubic charging infrastructure may be less of a priority. On the other hand, for households that plan to maintain a BEV as their sole vehicle or that require all their vehicles to be multi-functional, the widespread availability of public charging infrastructure with short recharge times may be an essential consideration. There are three basic types of chargers (Figure 5.3):

- AC Level 1 chargers operate at ordinary U.S. current, 120 V AC. They can use extension cords or a protected charging device that connects to an ordinary socket on a dedicated electrical circuit. Most PEVs come with a cordset for Level 1 charging. One hour of Level 1 charging will add 2 to 5 miles of electrical range to a PEV.[49]

- AC Level 2 chargers operate at 240 V AC for home installations (208 V AC for commercial installations). These chargers require a separate charging installation and a dedicated circuit of up to 100 amperes, or amps (for high power commercial installations). Operation at 30 amps, which is typical for residential chargers, will deliver 7.2 kW of power; operation at 80 amps will deliver 19.2 kW. AC Level 2 charging adds about 10 to 20 miles of electrical range per hour. Future, higher-power AC Level 3 charging (up to 130 kW) will be possible using three-phase power at commercial and industrial locations.[50]

- DC Fast Chargers operate at up to 500 V DC and most can add 50 miles of range in about 20 minutes.[51] Tesla Motors states that its Supercharger can add up to 170 miles of range to a Tesla Model S in 30 minutes.[52] PEVs require special on-board connectors and charging equipment circuits to use such stations. Unlike AC Level 1 and 2 chargers, which have a common standard connector in the United States, SAE J1772, there are three competing couplers (connectors) for DC fast chargers: CHAdeMO and SAE J1772 Combined Charging System (CCS or Combo) couplers and the Tesla Super Charger connection. Over 500 U.S. charging stations use the CHAdeMO coupler. The SAE J1772 CCS design allows a single coupler to be used for AC Level 1 and 2 and DC fast charging, eliminating the need for two separate charge connectors on a vehicle, one for AC charging and one for DC charging.[53]

Figure 5.3. Summary of the primary vehicle charging station categories[54]



Level 1 chargers can be integrated with a standard outlet, while Level 2 chargers require additional equipment. DC chargers are primarily used in commercial applications where rapid charging is an important priority. Other research found that home charging accounted for more than 80% of total energy transfers to PEVs by private owners [55] However, this fraction is decreasing over time as the availability of public chargers increases.

Federal, state, and local governments have made a vigorous effort to roll out public charging networks, and a number of firms have promoted workplace charging as well as charging stations at retail shopping locations. Table 5.5 shows an estimate of the public and private chargers (not counting residential chargers for home use) currently available; availability of such chargers is increasing rapidly.

Table 5.5. Number of Public and Private PEV Charging Stations in the United States[56]

	Stations	Outlets
Public	12,543	31,363
Private	2,426	4,965

Figures do not include residential chargers for home use.

Although virtually all current charging systems use a cable connector, it is possible to charge wirelessly using an electromagnetic field. Some new charging systems use this "inductive charging," avoiding the need to physically plug vehicles into a charger. There are already a number of inductive (wireless) EV charging systems on the market, but most current offerings are relatively low power. Automakers such as Nissan, Toyota, Hyundai, and BMW currently are pursuing higher-power inductive charging options, as high as 22 kW; however, these are not yet commercially available.

Deployment of residential charging stations in rural and suburban areas is relatively straightforward because a large proportion of dwelling units are capable of co-locating vehicle parking and electrical access at moderate cost. In urban areas, developing successful residential charging networks is more complicated because PEV owners are likely to demand the ability to charge their vehicles at locations close to their residences and to access chargers at their convenience. This may be difficult to achieve in densely populated urban areas where many residences do not have a garage or an assigned parking place. This is also an environment where land is both expensive and scarce, and construction costs for charging stations will likely be high.

An extensive network of public charging stations can help to allay “range anxiety,” the concern that a (pure battery electric) vehicle will lose its charge before reaching a desired destination, and to make such vehicles practical for longer trips. New business models have to be developed for these stations, but they cannot fully take the place of home charging. Although chargers are not capital intensive, land costs can be high, especially considering that even rapid charging can take a minimum of 20 minutes per vehicle. This may present an opportunity for business owners to recoup infrastructure investment through the increase in sales of goods and services, by adapting the current gasoline station model where the majority of profits are not realized from the direct sale of the fuel, but from the sale of consumables in the gasoline station. In the early years of PEV deployment, public charging stations may be underutilized, and the availability of home recharging will keep their utilization rather low even after significant numbers of PEVs are on the road.

Exacerbating the challenge, long-range travel is highly variable temporally and, given long charging times, major delays in accessing a charger could be a problem during peak travel periods unless substantial excess charging capacity is available. Also, extreme weather can greatly affect demand for public charging because high and low temperatures will both reduce PEV range and increase charging time.[a] Further study is warranted to better understand the relationship between charging infrastructure availability and PEV adoption rates.

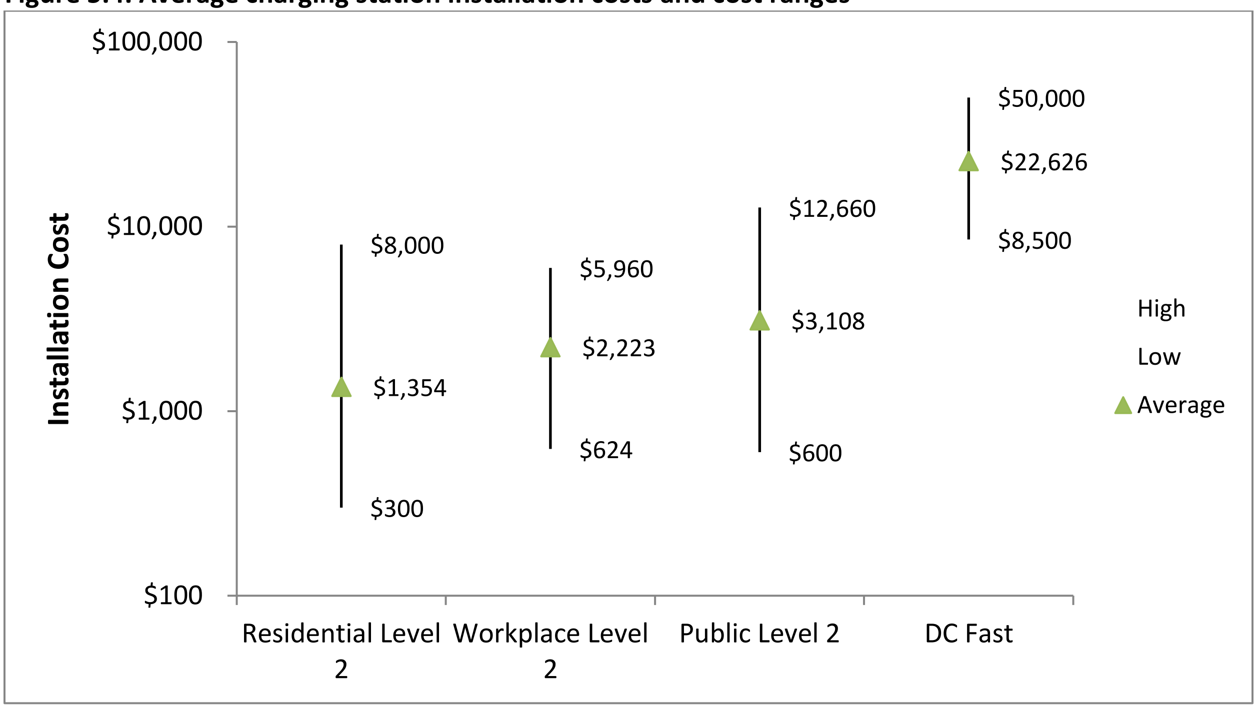
Upgrades to the current electrical grid can help to support large-scale deployment of PEVs. In particular, many local distribution substations and feeders may need to be upgraded to be able to handle increased PEV charging loads required by AC Level 2 chargers and DC chargers. Many utilities are in the process of implementing optional time-of-use pricing programs that provide consumers with lower-cost electricity during periods of low demand and excess supply. These programs can be complemented by outreach and education to consumers to encourage them to achieve maximum cost savings by recharging during off-peak periods. Smart grid enhancements may also help improve the overall business case for EVs by allowing them to provide ancillary services to the grid, for example, by providing battery storage to smooth demand fluctuations. The section on Interactions with Other Sectors (Section 5.5) discusses these issues in more detail.

[a] American Automobile Association tests showed range reductions for 105-mile-range BEVs (at 75°F) to 43 miles at 20°F and 69 miles at 95°F; for fast charging, the LEAF owner’s manual projects an increase from 30 to 90 minutes under cold temperatures and to 60 minutes under hot temperatures.

Charging station costs are highly variable and hard to predict due to permitting requirements that change with location, differences in accessibility of required electric service (for example, whether existing concrete must be removed and replaced to access electrical circuits), different features, and other factors (Figure 5.4). Also, costs have dropped over time, and equipment cost projections that are a few years old can be considerably higher than current projections. Currently, AC Level 2 home charging stations are available for as little as $500, with additional costs for installation and, if necessary, for installing a 240 V circuit. Public AC Level 2 stations are generally more expensive, as they require equipment to process payments (unless charging is free) and often require increased installation costs. Charger costs range from $2,300 to $6,000, but installation can be much more expensive.[57] [58] Garage chargers can be wall-mounted, and installation may cost only a few thousand dollars, especially if wires can be wall-mounted (inside a protective cover). Chargers located next to on-street parking spaces will likely be located on pedestals, must be weather resistant, and may require extensive concrete work to connect the charger to the nearest breaker box. In both cases, co-location of multiple chargers will probably require upgrades to wiring, breaker boxes, and possibly also the local transformer. Workplace installations of AC Level 2 chargers have had lower average costs than public installations due to increased flexibility in installation locations.

DC fast chargers, particularly those with higher capacity, can cost far more than AC Level 2 chargers. If a new transformer is required, this can add $10,000 to $20,000 to the cost. Permitting is also expensive, possibly up to $10,000. Other installation costs are likely to be similar to those of AC Level 2 stations.

Figure 5.4. Average charging station installation costs and cost ranges[59] [60] [61]



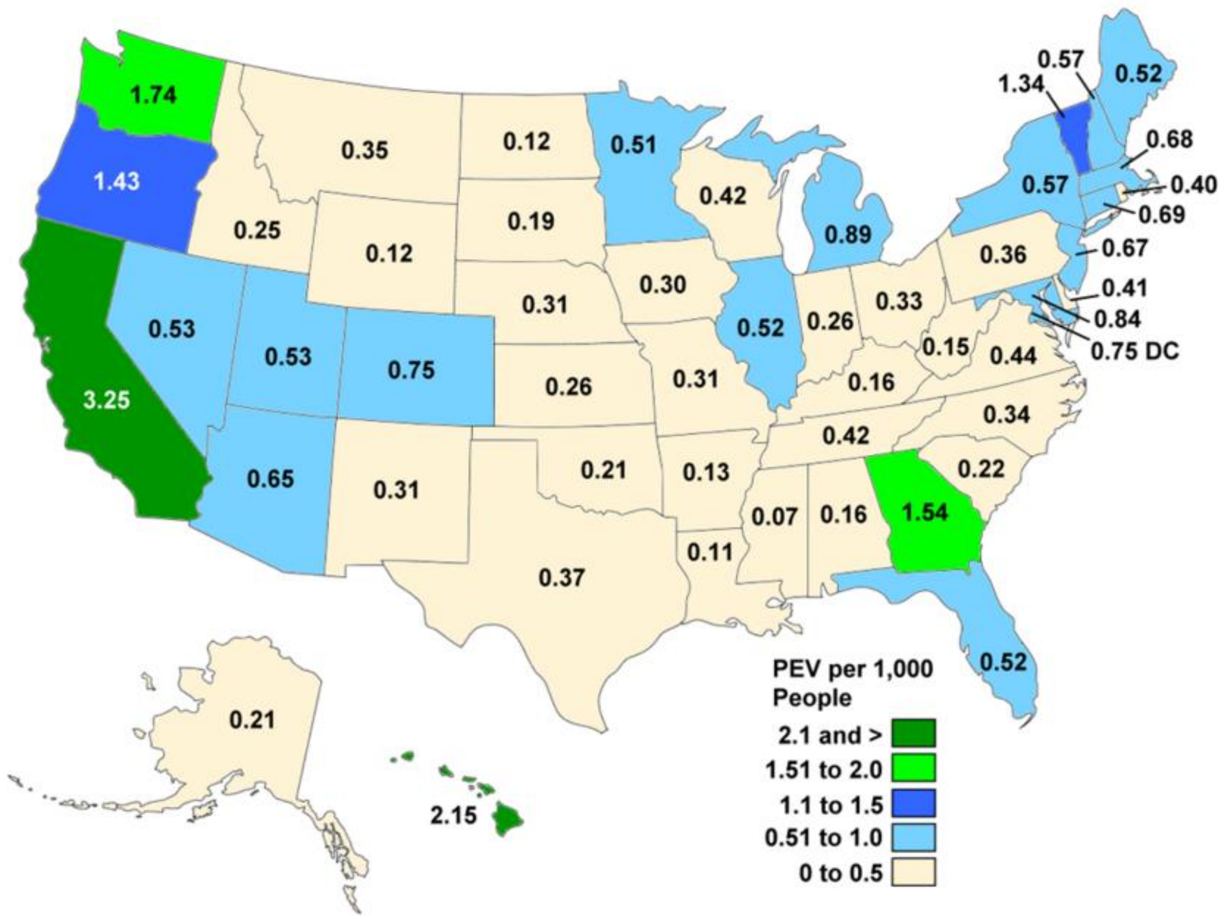
Data are from the DOE EV Project and ChargePoint America Project, which together installed almost 17,000 Level 2 charging stations and over 100 DC fast-charging stations between 2011 and 2013.

5.3 Metrics and Trends

5.3.1 Number and penetration of EVs

The first two mass-market PEV models, the Chevrolet Volt and the Nissan LEAF, were introduced into the U.S. market in December 2010, and 387,595 PEVs had been sold as of November 2015. Among these vehicles, 199,425 are BEVs and 188,337 are PHEVs. The PEV share of total car sales is about 1.4%, made up mostly by subcompacts, compacts, and large cars.[62] Because of the success of the large Tesla Model S sedan, and the sales dominance of the mid-size LEAF, BEVs are larger on average than PHEVs, which are primarily compacts and subcompacts. The fact that compliance BEVs[a] have been introduced in only a few states suggests a cost minimization strategy by many automakers. The general success of plug-in vehicles can be attributed primarily to shared success of multiple, nationally marketed models—the Plug-in Prius, the two Ford Energi PHEVs, the Volt, the LEAF, and the Tesla Model S.

Figure 5.5. PEV registrations per 1,000 people by state in 2014[63]



California has the highest PEV penetration of any state, followed by Washington, Oregon, and Georgia. PEV penetrations are generally highest on the West Coast and Northeast, and lower in Central and Southern states.

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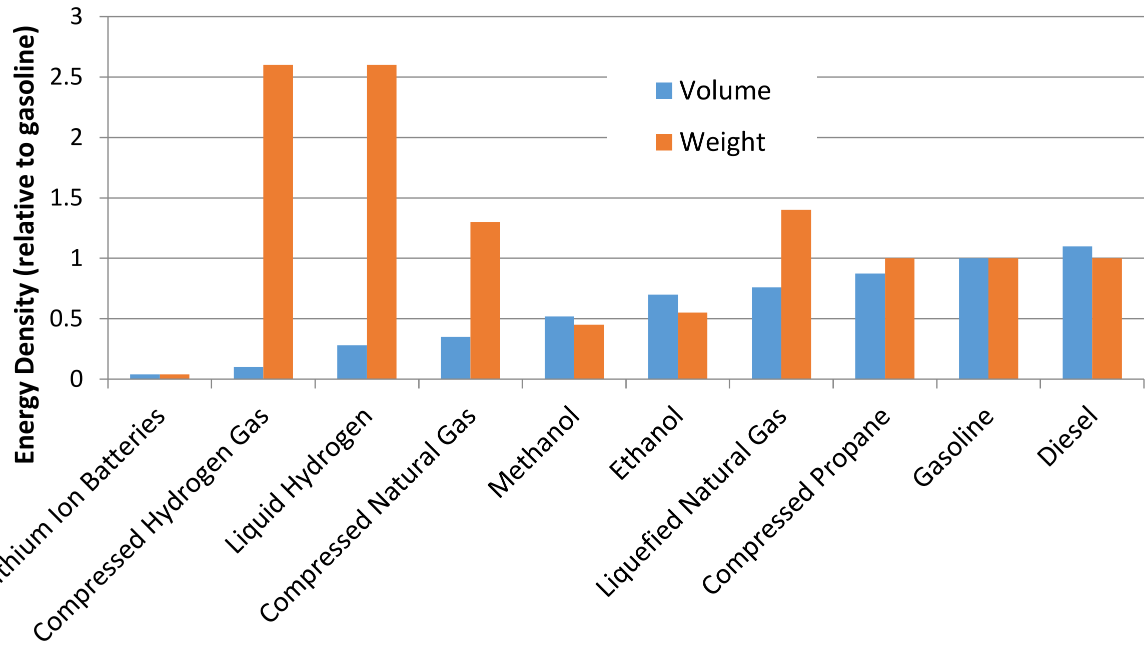
[a] Some states, California most notably, require that a certain fraction of all vehicles sold by all large automakers are zero-emissions vehicles. So-called "compliance vehicles" are primarily introduced to comply with such mandates and are not necessarily intended to be profitable themselves or to gain market share organically. They typically involve the conversion of an existing conventional model by replacing the engine with a battery pack, as opposed to development of a new PEV-specific model such as the Volt or LEAF.

5.3.2 Battery Technologies

Figure 5.6 compares energy densities of various transportation fuel types, revealing a primary challenge facing electricity use in vehicles that are not directly linked to the electric grid (all vehicles except electrified rail vehicles and trolleybuses). Lithium-ion (Li-ion) batteries, the most energy-dense, commercially available vehicle batteries, have energy densities that are a small fraction of the most common automotive fuels. Consequently, the electric range of PEVs will be constrained until next-generation battery technologies with increased energy density can be developed and commercialized. This is most constraining for BEVs, most of which have ranges near or below 100 miles. PHEVs avoid this range constraint but must deal with dual drivetrains, which add to cost.

Figure 5.6. Relative energy densities of various transportation fuels[64]



Lithium-ion batteries, which are used in essentially all electric vehicles, have energy storage densities that are roughly 20 times lower than conventional gasoline and diesel fuel. Higher energy densities are more favorable. Increasing the travel range of a BEV requires that its weight be increased significantly as well, thereby reducing its efficiency, all other design features being equal. Data does not consider weight of storage tanks or other equipment that the fuels require.

Batteries currently account for a quarter or more of the purchase cost of PEVs[a], but battery prices have dropped substantially in recent years. This is particularly the case for larger battery packs. Santini has estimated costs for large battery packs to be about $300/kWh, assuming a 1.5 price/cost factor.[65] McKinsey has estimated that battery pack costs for 2025 will be $160/kWh; the same 1.5 price/cost factor would yield a $240/kWh retail price equivalent for 2025. These projections are relatively close to the cost target that has been established by DOE's Vehicle Technologies Office (VTO)—$125/kW by 2022.[66] As battery costs continue to decrease, PEVs will become increasingly cost-competitive with comparable conventional vehicles.

[a] Batteries make up a greater fraction of total costs in longer-range vehicles, e.g., the batteries in forthcoming 200-mile-range BEVs will likely account for a significantly higher percentage of cost than the current generation of BEVs with roughly 100 miles of range.

5.3.3 Charging Infrastructure Technologies

A robust charging infrastructure is also an important enabler of increased market adoption of PEVs, and more specifically, BEVs. While many potential PEV purchasers can have easy access to home recharging through installation of chargers in home garages or garages in multi-family residences, public charging networks will also be necessary to allay range anxiety and to allow longer trips with BEVs. Although multiple organizations are building public chargers, currently there are only 30,000 or so public chargers available, most requiring hours for a single recharge. Even with fast chargers, recharging time is 30[a] minutes or more,[b] and that assumes the charger is not already in use. These issues may limit PEV growth in the near term, but such limitations can be reduced by increased investments in new charging infrastructure and in the development of higher- power batteries that can be charged more quickly.

5.3.4 Market Trends

Despite concerns about battery performance and charging infrastructure, other factors might argue for an optimistic future for vehicle electrification. First, despite the range limitations of BEVs, surveys of travel patterns show that even current BEVs can satisfy the great majority of travel requirements. The 2009 National Household Travel Survey showed that the average daily travel of rural and urban cars surveyed was only 34.18 miles and 23.14 miles, respectively.[67] PEVs may be particularly attractive for multi-vehicle households, which could also maintain a conventional vehicle. The PEV could then be used for shorter daily trips, with the conventional vehicle as an option for longer distance travel. With the proliferation of multi-vehicle households (in 2010, about 57% of all households had two or more vehicles)[68] and the availability of car-sharing services (as well as rental cars) that could be used for longer trips, the potential for many households to own at least one PEV is clear. Also, automakers are about to launch mass-market vehicles with 200-mile ranges, which will satisfy a much greater percentage of travel needs. The primary missing enabling factors are an inexpensive energy- (and power-) dense battery and a robust network of fast chargers. However, it is not yet clear whether mainstream consumers will accept 20- or 30-minute charging times, even if fast charging is required only occasionally, nor is it yet clear what portion of multi-vehicle households will accept vehicles that do not have full functionality for longer trips.

5.4 Technologies and Strategies

Successful electrification of transportation will require further development of several key technologies and systems, especially the following:

5.4.1 Energy Storage Costs

Current-generation Li-ion batteries are too expensive for EVs to be fully cost-competitive with comparable mass-market conventional vehicles. However, the high power capabilities of long-range Li-ion battery packs (e.g., those in the Tesla Model S) have driven success in the luxury/performance market. Accordingly, EVs are holding a sustainable minority share in this market. Major reductions in energy storage costs for Li-ion technology are needed for PEVs to gain substantial mass-market share. Successful development of next-generation battery chemistries, in particular lithium air (see Section 5.4.5), would help more cost-effective PEVs to gain market share, although long recharge times could remain a significant barrier.

[a] Usually to about 80% state of charge.

[b] As noted previously, charging time can double or triple at extreme temperatures.

5.4.2 Vehicle Load Reduction

PEV range, which is crucial to market success, is a function primarily of battery energy capacity and vehicle loads—vehicle weight, aerodynamic and tire losses, and heating and cooling loads (and other accessory losses, e.g., lighting). Minimizing these loads will allow both added range and improved performance. The efficiency of the electric drivetrain is also important to range and performance (e.g., minimization of electric motor losses and transmission losses).

5.4.3 Charging Technologies

Development of a robust charging infrastructure is an important component of the development of a successful PEV marketplace. AC Level 1 chargers use normal (120 V) house current; AC Level 2 chargers use higher voltage (240 V), generally used for electric clothes dryers and stoves; and DC Level fast chargers operate at even higher voltage (typically 208/480V AC three-phase input). Multiple manufacturers have developed new charging systems, and prices have dropped dramatically. Efforts are also underway to develop inductive "wireless" charging technologies that would allow PEVs to receive an electric charge while in motion.[69]

5.4.4 Standards

Standards must be rigorously implemented and updated for vehicle systems (especially to ensure safety for mechanics and first responders) and charging systems. Interoperability is highly desirable to ensure that vehicles can recharge at any charging station available. Unfortunately, there are three different and incompatible fast-charging technologies currently in use for vehicles.[a] Consolidation of these into one standard will help speed market adoption of PEVs.

5.4.5 Batteries

The vehicle battery pack represents the crucial technology for PEVs, currently representing at least 25% of total vehicle cost and largely determining vehicle range. Modern PHEVs and BEVs use Li-ion battery packs. Aside from continuing improvements in manufacturing techniques, pack designs, and supply chain management, and growing economies of scale as battery manufacturing ramps up, there are multiple opportunities to improve Li-ion technology—or to explore other battery chemistries—to reduce costs, increase battery-specific energy (the ability to store electrical energy, measured in kilowatt-hours per kilogram, or kWh/kg) and power (kilowatts per kilogram, or kW/kg), lengthen battery lifetimes, and improve safety. The following are several potential approaches:

- Improving Li-ion batteries, which is the subject of an intensive R&D campaign by private industry and government laboratories. Approaches being pursued by the Center for Electrochemical Energy Science (Northwestern University, University of Illinois at Urbana-Champaign, and Argonne National Laboratory) include:
    - Using silicon anodes protected by graphene[b] to prevent cracking of the anode as it expands and contracts

[a] The three are: the Japanese CHAdeMO standard; SAE's Combo Charging System (CCS); and the Tesla Supercharger system. China has also proposed its own system (GB). Each has different couplers, so vehicles with one type of coupler cannot use another system without an adapter.

[b] Graphene is a two-dimensional sheet of carbon, one atom thick, in a honeycomb pattern, which has incredible strength.

    - Using lithium-manganese-oxide cathodes protected by graphene to prevent the manganese from dissolving
    - Exploring other materials and coatings for the cathode
    - Substituting block copolymers to replace lithium
    - Using waste silicon powder (from chip making) in battery manufacture at lower cost

- Using solid-state batteries to replace the liquid electrolyte with a solid, which would eliminate leakage, greatly reduce fire danger, and reduce temperature sensitivity and cooling requirements.
- Adopting aluminum-ion batteries using an aluminum anode.
- Using lithium-sulfur batteries, which have higher theoretical energy density than Li-ion batteries and should be cheaper. A key research aim is to improve their ability to cycle.
- Reducing battery weight by using metal-air batteries, including lithium air, which have metal anodes and use air as a cathode. Lithium-air batteries offer theoretical energy densities of 5,000 watt-hours per kilogram (Wh/kg), compared to about 100-200 Wh/kg for Li-ion batteries.[70] Gasoline's energy density is about 13,000 Wh/kg.[71] At 5,000 Wh/kg, the Tesla model S 250-mile (85 kWh) battery pack, which weighs 1,200 pounds, would weigh about 37 pounds. However, the achievable energy densities of metal-air batteries will certainly be significantly lower than the theoretical level, probably less than ten times the energy density of Li-ion storage. However, even at an energy density multiple of three or five, these batteries could transform the prospects for EVs if they were affordable and capable of rapid recharge. There remain several major challenges to developing successful lithium air batteries, including preventing blockage of the cathode, damage from water vapor, low electrical efficiency, and long-term stability.

With long time frames for introducing new battery chemistries, improvements in Li-ion batteries may be the crucial determinant of PEV success for the foreseeable future. Multiple research teams sponsored by national governments and private industry are striving to decrease costs, increase safety (Li-ion batteries have fire safety issues[a]), increase longevity, allow more rapid recharging, and maximize specific energy.

The extent to which these technical advances, economies of scale, and "learning through doing" are able to drive down battery prices is a key arbiter of PEV success. The DOE target for battery pack costs is $125/kWh, which is meant to represent the point where plug-in vehicles are competitive with ICE vehicles. However, recent economic evaluations have concluded that pack costs of $250/kWh represent a breakeven point at gasoline prices of $3.00–$4.50/gallon.[72]

Tracking actual costs of battery packs is difficult for a number of reasons, including: (1) the multiple battery chemistries and cell and pack designs being manufactured, (2) industry secrecy, (3) possible direct cost reduction incentives from battery pack and vehicle manufacturers intent on gaining market share, (4) different definitions of battery capacity (both total kWh and "available" kWh[b] are used, but this is not always specified), and (5) different definitions of manufacturer costs, which are not always carefully explained in industry statements and literature. An analysis of more than 80 cost estimates by Nykvist and Nilsson concluded that current battery pack costs are substantially lower than values often cited—for 2014, about $410/kWh on an industry-wide basis and $300/kWh for industry leaders such as Tesla and Nissan.[73] Estimated costs for industry leaders have been declining by about 8% per year since

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[a] It is useful to note that such issues are not unique to batteries; gasoline is also highly flammable and explosive.
[b] PEVs cannot access the full kWh capacity in a battery because deep capacity drawdowns—below 20%—may degrade batteries and reduce their lifetime.

2007 and may well continue to decline at that rate. The key forces behind the decline are reductions in input material costs, greater economies of scale, and learning (as production ramps up) better production techniques. Costs for 2017–2018 are projected at $230/kWh,[74] an estimate compatible with McKinsey's 2012 estimate of $200/kWh by 2020 and $160/kWh by 2025.[75] Costs of PEVs at new large-scale plants (e.g., Tesla's Gigafactory) are projected at about $200/kWh for pack production levels above 100,000 per year.[76]

Santini has produced PEV vehicle and cost estimates for current-generation Li-ion battery manufacturing.[77] Two independent models developed by Argonne National Laboratory and The German Aerospace Center were used to inform these estimates. Cost estimates for PEV batteries with capacities of 15 kWh (the Nissan LEAF battery pack is 24 kWh) or higher were estimated to be about $300/kWh. However, this estimate was made in 2012–2013 for an unspecified future high-volume production level. McKinsey's 2012 estimate for 2020 is consistent with the lower and earlier 2010 estimates of Santini, Gallagher, and Nelson[78]. They estimated that at high volume, for a 33 kWh total (25 kWh useable) battery pack, the average costs at the manufacturer's factory gate could be less than $200/kWh. Note that the Argonne model predicts that per-kWh costs decline with total pack kWh. Most studies cited failed to isolate this effect. Tesla packs have about three times the kWh capacity of Nissan LEAF packs. Santini estimated that the costs of adding power to large Li-ion packs were very low, which is consistent with the current market success and "affordability" (in the high-end luxury/performance market) of the high-power, very-high-performance Tesla EVs.[79]

The results of these studies imply that battery pack costs may well continue to drop, thereby increasing the value proposition of PEVs relative to comparable ICE vehicles.

Autonomous Vehicles

In recent years there has been much discussion of, and progress toward, the development of autonomous vehicles, which are able to navigate highways and streets without driver input (aside from initial programming or destination instructions). Autonomous driving could substantially increase vehicle efficiency by reducing acceleration and deceleration events, eliminating congestion slowdowns from accidents, and allowing substantial reductions in vehicle spacing, which in turn would reduce aerodynamic drag. There has been speculation that fully autonomous vehicles could be made much lighter (further reducing energy use) because crash protection could be reduced or even removed. However, such further "lightweighting" would have to wait until all road vehicles are connected and communicating at all times, which is not likely during the next several decades. Whether autonomous vehicles can actually reduce net energy consumption depends on increased vehicle efficiency and rideshare potential on one hand, and increased overall travel demand and addition of "empty trips" with no passengers on the other. Because autonomous vehicles can be sent back to parking areas for charging and/or for dispatch to serve other consumers, they could promote both electrification and vehicle sharing, with strong implications for both energy use and travel. Further analysis and experience is required before reliable predictions of potential energy use impacts can be made.

5.5 Interactions with Other Sectors

5.5.1 Interaction with Other Market Sectors

Due to the relatively low current penetration rate of PEVs, interactions between electricity consumption in the transportation and residential sectors are currently limited. However, as the penetration of personal PEVs increases, interactions will increase, primarily due to home vehicle charging. The 1.7 kW load of an AC Level 1 charger is less than that of a moderately sized residential central air conditioning system, and therefore could likely be absorbed into the usage profile of a typical home. However, the 7 kW or greater load of an AC Level 2 charger will exceed the current peak consumption rate of many single-family homes, and the simultaneous use of numerous AC Level 2 charging stations in a single neighborhood could pose technical challenges to local substations if charging is not properly managed. This issue could also be addressed by utility upgrades to the substations (similar to upgrades that have been required when smaller homes were initially built and then subsequently replaced by larger homes with dual air-conditioning systems).

In addition to peak effects, home vehicle charging will also increase total residential electricity consumption. A compact PEV that is driven 12,000 electric miles per year will consume approximately 3,600 kWh of energy (assuming 0.30 kWh per mile), which is roughly 33% of the current consumption of a typical residential utility customer.[80] However, this increase in *average* demand does not pose the same technical challenges as potential *peak* demand impacts. The increase in *total* residential electricity consumption will also not be large in aggregate unless PEVs become more widespread.

There will be similar interactions with the commercial sector related to consumers who choose to charge their personal vehicles at businesses or institutions where they work. Such charging will increase total electricity consumption in the commercial sector and contribute to increased peak loads, particularly in warm climates where the summer peak occurs in the middle of the afternoon if the workplace charges are still ongoing during this time period. In addition to providing charging stations for employees' personal vehicles, businesses may choose to use EVs for their own operations—e.g., delivery or service vehicles. These would also typically be charged at night at commercial buildings and therefore would have increased total commercial electricity consumption, but would have minimal peak load impacts.

There are also opportunities for synergies between the transportation and residential or commercial sectors, particularly for consumers who are reliant on distributed energy resources. For example, EVs can be integrated into demand response programs in which utilities provide incentives for consumers who reduce their electricity consumption during periods of high demand. Such programs are currently more common in commercial buildings, but there is potential for more applications in the residential sector in the future.

PEVs can provide a source of backup power in the case of a power outage. A fully charged Nissan LEAF stores 24 kWh of energy, which is sufficient to power a modest home for one or two days, or even longer if power use is restricted to vital services and appliances. Nissan began to implement PEV backup services in Japan in the wake of the 2011 tsunami and associated power outages, and the company is exploring similar possibilities in the United States and other markets.[81] However, technical improvements will be required to ensure that batteries are able to handle such a duty cycle.[a] Such two-

[a] Batteries for automotive use are currently being designed for maximum range. Designing batteries to also handle a duty cycle for distributed generation requires engineering design trade-offs with maximum range, and so is not a priority for commercial EVs.

way vehicle-to-building (V2B) or vehicle-to-home (V2H) interactions can provide short-term energy until power is restored by the utility to cover critical power needs for medical and other purposes. These V2B/V2H interactions can generally be implemented even in the absence of comprehensive smart grid technology, as they potentially involve only two actors (a single vehicle and a single building).

In addition, the storage capacity of PEVs could someday be used to balance the real-time variability of distributed generation resources.[a] For example, buildings that are powered by rooftop solar panels can charge connected vehicles during periods where generation outpaces demand, and withdraw energy from vehicles when demand exceeds generation, just as they would with any storage resource.

5.5.2 Grid Impacts

As the market penetration of electrified transportation increases, transportation energy that has traditionally been provided by petroleum-based fossil fuels will increasingly be provided by electricity from the grid. Such electricity can be generated from a variety of primary sources, including fossil fuels and nuclear, hydroelectric, wind, and solar resources. This shift in energy consumption may provide a range of benefits to individual consumers and society as a whole. For consumers, electric fuel sources will likely be cheaper than gasoline from the pump. Furthermore, electricity can be generated from renewable resources, resulting in true zero-emissions transportation. Increased electrification of transportation may also provide the national security benefit of reduced reliance on imported oil products.

Yet there are costs and challenges associated with increased use of electric transportation as well. While energy consumption will shift away from inefficient ICEs and oil-based fuel sources, electricity demand will increase. Depending on its extent, this increased electricity demand may strain the existing electric grid and could possibly require new investments in generation, transmission, and distribution infrastructure. In addition to increasing total electricity demand, electricity consumption patterns may change as well, resulting in new issues that must be considered and addressed. The utility industry is currently undergoing grid modernization actions designed to maintain system reliability as electricity demand profiles continue to evolve. As the modern grid is developed, utility planners will have to consider and account for the additional load that will result from transportation electrification, as well as the reduction in load from increased efficiency (see previous sections in this document) and the increasing generation from renewable sources. Alternatively, a modern grid can also benefit from intelligently managed PEV charging, as is discussed further below. With flat, and in some cases reduced, load growth due to effective energy efficiency technology applications (see prior chapters), the increased load from transportation may prove beneficial, ensuring maximum utility system asset utilization.

Therefore, the economic, societal, and environmental impacts of a shift toward electric transportation will depend on how the electricity is generated, when and where it is consumed, and a number of other factors. The following section focuses primarily on the grid impacts associated with charging battery-powered vehicles while they are not in use—specifically mass-market LDVs. Impacts from increased use of rail and other forms of transportation that are directly powered while in operation are not anticipated to be significant, due to the relatively small projected increase in electricity consumption from these technologies.

[a] The same concern that is discussed in the previous footnote applies here as well.

5.5.3 Impacts Based on Technology Characteristics

The grid impact that results from increased electrification of transportation will depend on both the specific characteristics of the vehicles and charging infrastructure that are interacting with the grid, and the strategies being used to manage those interactions.

As discussed previously, there are three primary classes of vehicle chargers that each draw electricity from the grid at a different rate. AC Level 1 chargers draw approximately 1.7 kW of power; AC Level 2 chargers typically draw approximately 7 kW of power, but can draw as much as 19.2 kW. DC Fast Chargers can charge at a rate of 50 kW or even greater. Tesla Motors is developing a network of public “Superchargers” that can charge at a rate of up to 120 kW. The battery capacity of a vehicle being charged and the state of charge of the battery also directly influence the amount of time required to achieve a full charge, and therefore the period of time over which grid impacts may occur. Larger electrified vehicles, such as freight trucks and buses, are not currently in widespread use but would presumably also be equipped with larger batteries and use AC Level 2 or DC Fast Charging technology.

5.5.4 Impacts Based on Consumer Charging Patterns

The most significant impacts to the grid will likely be related to increases in instantaneous power demand (or peak load) as opposed to total energy consumption levels over the course of a year. The extent of these impacts will strongly depend on consumer battery depletion levels, charging patterns, and the automated or controlled charging mechanisms that are implemented.

Absent any external incentives or costs, most consumers will choose to charge their vehicles whenever it is most convenient for them. For many, this will be when they return to their home charger at the end of the day. If a significant number of consumers follow this charging pattern and do not elect to take advantage of time-of-use rates and delayed charging, a rapid increase in instantaneous power demand in the early evening would likely result, particularly if there is widespread use of AC Level 2 charging infrastructure.

One study has suggested that a large PEV fleet using AC Level 1 charging infrastructure would not significantly increase peak power demand, but that similar uncontrolled use of AC Level 2 charging infrastructure would result in increased winter and summer demand peaks.[82] More recent research has shown that home overnight charging takes only about three hours for a typical vehicle and that consumers who utilize time-of-use pricing schemes do shift their vehicle charging to off-peak periods as might be expected.[83] Furthermore, 57% of survey respondents indicated that they changed their utility rate subscription as a result of obtaining a PEV.[84] The use of controlled charging technologies or other techniques to promote off-peak charging can help mitigate or eliminate the need for investments in new peak generation capacity and can even provide additional benefits to the power system, as discussed in more detail below.

5.5.5 Charging at Work

Increased penetration of charging infrastructure away from the home—at work or in public places—would spread out load increases throughout the day, thereby reducing this peak load effect and providing other grid benefits. There may also be diminishing marginal returns from investments in workplace charging infrastructure. One study found that 80% of the total potential benefit can be obtained while only providing work charging to 10% of the population.[85]

5.5.6 Controlled Charging

Previous discussions have focused on uncontrolled charging when vehicles begin to charge the moment they are plugged in and continue to charge until they are unplugged or the battery is fully charged. However, such instantaneous charging is not typically required by most consumers, who simply require that their vehicle has a full charge by the time their next trip begins. Smart, "controlled charging" techniques may be implemented to reduce the total cost of providing consumers with the service they desire—a fully charged battery when they start a trip.

Such systems are typically based upon the concept of time-varying pricing, whereby consumers are charged a rate for the electricity consumption that varies throughout the day, rather than a single fixed rate, as is more common today. Time-varying pricing enables electric service providers to charge consumers a rate that more closely matches their actual marginal cost of electricity provision. Such rate designs also provide a price signal that encourages consumers to charge their vehicles when the electricity price, and therefore the cost of providing electricity, is low. Such a system could be implemented through prices that are constantly adjusted in real time based on system conditions. Alternatively, a more simplified block-pricing structure with fixed peak periods, fixed prices, or both might be considered. Ideally, charging infrastructure would be developed with the ability to automatically respond to these price signals so that consumers could program their vehicles to only charge when the real-time electricity price is below a certain threshold. Yet, even if chargers do not have automated response capabilities, block-pricing would encourage consumers to manually delay their charging until prices and demand are lower and generation capacity is more readily available. In the absence of time-varying pricing, consumers could also cede some control of their vehicle charging directly to their utility, perhaps in exchange for a lower rate or monthly bill credit. One study has shown that controlled charging may reduce the cost of electricity generation used for charging by 23% to 34%.[86] Controlled charging can be further facilitated through education and outreach programs from the utility to the PEV consumer that provide information on the potential cost-benefits of participating in time-of-use electricity rate programs.

5.5.7 Impacts in Systems with High Levels of Renewable Resources

Renewable electricity generation capacity is increasing rapidly in the United States. Much of this new capacity is in the form of variable energy resources (VERs) such as wind and solar, which have variable output profiles that are dependent on environmental conditions. Bursts of wind can increase the amount of energy being supplied to a power system over short timescales, while passing clouds can similarly decrease solar power availability. This variability must be balanced by other resources in the system—both supply and demand resources—to ensure that energy supply is equal to demand in real time.

As previously discussed, one concern related to uncontrolled PEV charging patterns is the potential for an increased evening electricity demand peak. This issue may be further intensified in regions with large penetrations of renewable resources, particularly solar. For example, in California, where renewable resource penetrations are anticipated to grow significantly in coming years, the spring and fall evening demand peak corresponds closely with the natural evening decrease in solar generation as the sun sets. This period also corresponds with the time that many consumers are returning home and turning on air conditioners, doing laundry, cooking, watching television, and charging their vehicles. In the absence of other action, this may necessitate investments in fast-response generation facilities that are capable of rapidly increasing and decreasing their output levels. This technical challenge is by no means a direct consequence of PEV charging alone; it stems primarily from increasing solar generation levels and would be an issue even in the absence of PEV charging. However, large, uncontrolled evening PEV charging loads may contribute to and intensify these concerns.

PEVs also can provide a significant benefit to power systems during this evening ramp period, provided that controlled charging and two-way vehicle-to-grid capabilities (discussed further below) are available. Most PEV owners do not completely deplete their battery during a typical day of driving and instead return home with excess energy stored in their vehicle batteries. The grid could therefore draw upon this capacity to help serve demand during the evening ramp, thereby offsetting the need for more-flexible thermal generation units. This would necessitate the presence of a modernized grid and participation by PEV owners—which could be encouraged either through price signals or some other incentive framework—as well as advanced battery technologies that can support increased duty cycles.

There are also additional opportunities for both power system operators and PEV owners to benefit in systems with high renewable penetration levels. Wind generation tends to peak overnight when electricity demand is low. This can lead to periods of excess power in the system when wind generators are sometimes forced to curtail their generation to maintain a balance between supply and demand. In some cases, wholesale electricity prices may even become negative as wind generators are willing to pay a small amount to avoid curtailment so they are able to claim a federal production tax credit, or alternatively thermal generators may be willing to pay to generate and avoid costly unit shutdowns. Most PEVs will be primarily charged overnight and therefore would have an ideal load profile for taking advantage of these system conditions. In addition to decreasing the cost of charging for consumers, this would help to reduce wind curtailments and support grid stability. In a study of the PJM system, for example, controlled charging resulted in net positive social benefits when wind generation served 20% of total demand, but net negative social benefits under current conditions.[87]

5.5.8 Vehicle-to-Grid and System Balancing

In addition to capitalizing on lower overnight electricity prices in regions with large amounts of wind generation, PEVs that are charged intelligently can also support grid reliability over short time horizons. All power systems maintain reserve capacity that is capable of responding to changes in system conditions over various timescales. Regulation and frequency reserves are provided by generation, demand response, or storage resources that are capable of responding to automated signals to either increase or decrease total power in the system in a matter of seconds or faster. Longer-term spinning and non-spinning operating reserves are also maintained that can respond to instructions to change generation levels over a period of roughly 10 to 30 minutes.

In many other applications, demand response programs offer incentives to customers to reduce power consumption over the short term—for example, by temporarily shutting off air conditioners or hot water heaters, or by reducing industrial output. With PEVs, a reduction in charging rate would likely be imperceptible to a consumer who typically only requires that the vehicle receives a full charge over a multi-hour period. Therefore, PEVs potentially have great flexibility in charging schedules and are well-suited to provide short-term demand response, regulation, and frequency control. If managed appropriately, this flexibility could be a valuable resource for power systems, particularly those with high penetration of VERs.

There are two tiers of such interactions between vehicles and the grid that could be implemented to support grid reliability. One-way interactions involve varying charging rates in real time to complement net load variability. For example, if wind generation diminishes suddenly, charging rates could be increased for PEVs that are actively charging to reduce loads and help balance supply with demand. Two-way V2G interaction would additionally enable a transfer of energy from vehicle batteries back to the grid, allowing them to serve as a power supplier during periods of high demand. This would potentially double their beneficial grid impact, allowing vehicles to provide twice as much balancing capacity. There are concerns about the negative effect that the more frequent V2G charge/discharge cycles of two-way V2G life will have on battery life. However, such interactions would also benefit consumers by allowing them to automatically charge the PEVs when electricity prices are low and potentially generate additional revenue by selling stored energy back to the grid. While some research-oriented V2G pilot projects have been implemented across the United States, these services are not yet available to the typical consumer or electric utility.

V2G interactions could be implemented based on short-term price signals, but such interactions could also be facilitated more directly based on automated signals that are already generated by a power system. In the United States, power systems target a grid frequency of 60 hertz (Hz). However, the actual frequency varies naturally around this target as a result of supply and demand imbalances. If frequency drops below 60 Hz, the grid has an undersupply; whereas, if the frequency increases above 60 Hz, there is an oversupply. A PEV charger could automatically detect these changes and adjust its charging rate accordingly, increasing charging when frequency exceeds 60 Hz and decreasing charging when it is below 60 Hz (or some alternative thresholds, such as 60.1 Hz and 59.9 Hz). This approach has a distinct advantage over others, as grid frequency can already be easily detected through a standard connection, and no additional external communication technologies or protocols are needed. Since such frequency response service has value to grid operators, financial incentives could be provided to PEV owners who choose to participate.

One study of the Northwest Power Pool found that if about 13% of all vehicles in the region were electrified and equipped with one-way power flow/control capabilities, these vehicles could provide the 3.7 GW of additional balancing required to support 10 GW of new wind capacity predicted between 2012 and 2019.[88] Two-way V2G would decrease this requirement by about 30% to 35%.[89] It will be important to fully understand both the costs and benefits of utilizing PEVs in this manner, i.e., the value of the balancing versus the increased vehicle complexity and potential negative impacts to battery life.

5.6 Markets and Market Actors

5.6.1 Light-Duty Consumers

Much of the growth in electrified transportation over the next several decades will likely take place in the LDV market. Growth will be driven primarily by individual consumers who are purchasing vehicles for personal use. Growth may also be driven by use of LDVs by federal, state, and local governments, as well as private corporations both for internal use (e.g., delivery and service vehicles) and customer-facing use (e.g., taxis and ride sharing). PEVs are particularly attractive for such uses, as their relative efficiency gains over traditional ICE vehicles are even greater in urban driving environments. The potential adoption of electrified LDVs will be affected by a variety of factors. While PEV adoption is still in its early stages, a number of studies have attempted to identify the primary factors that influence consumer choice between conventional and electrified LDVs.

Education and awareness campaigns can help consumers to consider the potential for a PEV to meet or exceed their light-duty transportation requirements. The industry has early experience with current PEV customers that has helped to frame the critical questions and concerns that must be answered before a consumer will make the paradigm change from an internal combustion fuel-only vehicle to either one of the PEV models—BEV or PHEV. The challenge will be to use this knowledge to create awareness campaigns that attract the attention of currently non-interested, non-PEV-aware consumers.

Two primary factors must be considered. First, most consumers that would consider purchasing a BEV have some amount of “range anxiety,” or the concern that a vehicle will lose its charge before reaching a desired destination. This is not a concern for PHEVs, which can also operate on gasoline when their battery is depleted. This anxiety is closely tied to driving patterns, battery capacity, the availability of public charging infrastructure, and the time required to recharge a battery pack. Since range anxiety is only applicable to BEVs, educating consumers on the benefits of PHEV options that do not have the same range limitations can help speed adoption of PEVs. The second primary factor influencing purchase decisions is the extra up-front cost of a PEV compared to a conventional gasoline-power vehicle. While incentives exist to reduce this cost premium, and PEVs typically have lower fuel and operating costs that allow some or all of the premium to be recovered over the vehicle’s lifetime, many consumers are hesitant to make the required larger up-front investment because they have not developed a clear value proposition for PEVs like they have for other high-cost LDV options such as SUVs and pick-up trucks. Some care must be exercised when making vehicle comparisons based purely on cost, as consumers also consider a range of additional factors when purchasing a vehicle, including comfort, size, travel range, refueling/charging time, safety, and overall driving experience. This is clearly shown in the widespread purchase of SUVs, pick-up trucks, and luxury vehicles, despite their high costs of ownership. The general automotive-consuming public has not yet widely accepted the value proposition offered by PEVs; however, there is potential for this to occur.

One study has shown that U.S. consumers prefer low electric range PHEVs with 300-mile overall range, despite greater subsidies for BEVs.[90] Other studies have found that there is typically more support for BEVs from younger, well-educated, environmentally aware consumers[91] and those who are considering a BEV as a potential second vehicle,[92] though these dynamics may change if and when PEVs achieve more mainstream acceptance. Krupa et al. find that those who care about reducing energy consumption and emissions are 71 and 44 times, respectively, more likely to say they are willing to purchase a BEV as opposed to an ICE.[93] However, such consumers still have a willingness-to-pay of no more than several thousand dollars. Higher up-front cost and BEV range anxiety were identified as the biggest concerns and obstacles to greater adoption.

Car purchases are also relatively infrequent for most consumers; therefore, even if consumers are generally interested in obtaining a PEV, it may take several years for them to actually purchase one. Furthermore many purchasers are not interested in a small compact car and are instead interested in a larger car, truck, or SUV, which currently have limited PEV model offerings. As a result, widespread PEV adoption may take time to materialize, particularly if larger PEVs do not become more widely available and consumer preferences do not change. A recent survey found that only 24% of respondents were even considering purchasing a small sedan.[94] Some 68% of respondents indicated that they would consider paying a premium for an EV, but an HEV with a $2,000 premium was preferred to a PHEV with a $4,000 premium. Half of the respondents said that availability of wireless charging would increase their willingness to consider a BEV. This information validates the need for the PEV industry to increase its awareness activities to better inform the consuming public on the value proposition for the family of EVs.

5.6.2 Governments

New York City attempted to institute a series of mandates and financial incentives for fuel-efficient, hybrid taxis in the mid-2000s. While these efforts were eventually halted due to a legal challenge, hybrids still make up 60% of the taxi fleet in New York City.[95] A similar push for PEV taxis could help PEV penetration reach the critical mass that is needed to support public charging infrastructure and increased adoption by consumers, provided that PEVs will meet the range and service requirements of an urban taxi fleet. Many cities have also begun to consider electrifying their bus systems. However, the market for these technologies is still immature, and the charging requirements present unique challenges for buses that operate on fixed schedules. In addition to cities that may have an interest in purchasing electrified bus fleets for their transit systems, other government agencies could become consumers of PEVs for their own use (e.g., police, post office, health and environmental inspectors, park rangers).

Non-freight rail in the United States is already largely electrified, and it is unlikely that freight rail will become significantly electrified in the near future. Some efforts are under way to increase electrified passenger rail travel in the United States, most notably in California and to some extent in the Northeast. Intercity rail travel accounted for 6.8 billion p-mi in 2013, roughly 0.1% of total p-mi traveled in the United States, and 2 trillion Btu (586 million kWh) of end use electricity consumption. It has been estimated that by 2040 the proposed California high-speed-rail corridor could have between 17 and 26 million annual VMT.[96] Electricity consumption for rail travel is difficult to predict as it depends on train size, speed, efficiency, and passenger load; however, current data suggest a possible range between 21 and 58 kWh per VMT.[97] Given these assumptions, the resultant annual energy consumption of such a system would fall between 1.2 and 5.0 trillion Btu. Therefore, the new California system alone could potentially increase electricity consumption for passenger rail travel by 50% to 250% nationwide. However, given U.S. consumer preferences for highway and air travel, such growth is still relatively small compared to the potential for increased electricity consumption from electrification of the LDV fleet.

5.6.3 Vehicle Manufacturers

EV manufacturers are currently focused primarily on developing PHEVs and BEVs with larger batteries, and therefore a greater travel range, to dispel concerns over range anxiety. They are also aiming to reduce costs to achieve approximate price parity with conventional vehicles. However, much of the cost premium of PEVs is due to battery costs.

There is some division between manufacturers over the development of BEVs as opposed PHEVs. Most notably, Honda has not yet announced plans to develop a BEV that is intended for mass-market consumption,[a] opting instead for PHEVs, and has longer-term plans to introduce fuel-cell vehicles. Chevrolet originally opted to develop a PHEV (the Volt) as their first mass market PEV, though they will also release a BEV (the Bolt) in 2017. Conversely, Nissan chose to develop a BEV (the LEAF) as their first mass market PEV. The Tesla S currently stands apart from the field due to its extended range and its large price tag, but it has proven that BEVs can gain a foothold in the luxury car market.

A number of manufacturers that typically serve the luxury market, including BMW, Porsche, and Audi, are starting to follow suit by introducing their own line of PEVs. Other manufacturers are also beginning to announce new models that can compete with the range of the Tesla Model S, including Chevrolet,

[a] Honda did sell the Fit BEV between 2012 and 2014; however, only 1,100 were manufactured, and they were generally considered to be “compliance vehicles” as they were only sold in a handful states with ZEV mandates.

which has plans to introduce the Bolt in 2016 as a crossover with a 200-mile range. The electric SUV market is still in its infancy, but momentum has grown since Porsche introduced the Cayenne PHEV in late 2014, BMW introduced the X5 PHEV in 2015, and Tesla began taking orders for the Model X also in 2015, and other manufacturers will be joining that market shortly.[a] Increased vehicle choice will likely be a net positive for PEV adoption overall.

A major positive feature of several of the new PEV models is that they are expressly designed as PEVs, rather than being converted conventional vehicles with electric or hybrid electric drivetrains substituted for conventional ICE drivetrains. These new designs indicate their manufacturers' intention to do more than just comply with the Zero Emission Vehicle (ZEV) mandates of California and other states. Automakers clearly are going after a market they believe will grow, with uniquely designed vehicles that take account of both the special requirements and the potential advantages of battery-powered vehicles. PEVs have more to gain from reduced weight than conventional vehicles because of their range issues, and many of the new PEVs use very lightweight materials. For example, the Tesla S uses an all-aluminum body, and both the BMW i3 (BEV) and i8 (PHEV) use large amounts of carbon fiber composite. Furthermore, the purpose-built design allows manufacturers to use the battery as an inherent part of the vehicle structure, saving weight, improving crash protection, and reducing the vehicle's center of gravity by placing the battery very low on the vehicle.

5.6.4 Charging Station Providers

The availability of public charging stations can be a major factor in dispelling consumer range anxiety and increasing BEV adoption rates. However, in early stages of BEV adoption, public charging stations will likely be underutilized and therefore may not provide sufficient returns to attract private investments. It is also difficult for developers to properly estimate demand for charging stations in an immature market where costs and consumer perceptions are constantly changing. Yet, a certain level of infrastructure availability may be required by consumers before they are comfortable purchasing enough BEVs to keep charging stations well-utilized. As such, governments, electric utilities, and other public entities (as well as automakers) may consider developing or subsidizing public charging stations as a social service to encourage increased BEV adoption. According to a recent survey, increased availability of public infrastructure makes consumers more likely to consider BEVs, even though most would still charge at home overnight.[98] Even if they overwhelmingly charge at home, consumers are still likely to be worried about the small number of trips where a single charge is not sufficient. The presence of public chargers may be enough to ease range anxiety in these cases, but this assumes that the problem of excessive charging time—even with fast chargers—can be overcome.[b]

However, some maintain that while cities should foster a supportive environment for charging infrastructure—through effective permitting, zoning, and codes—they should only offer direct financial incentives in select circumstances, because fee-based PEV charging is a viable business opportunity.[99] Subscription-based business models (e.g., a yearly fee for unlimited use) also may be more effective than charging per unit of electricity consumed for charging. In addition to public and third-party charging stations, Tesla is developing its own network of Superchargers that are free for all Tesla owners, essentially wrapping the cost of this provision into the price of each new vehicle. Some businesses will view providing charging stations as useful for attracting customers or for retaining

[a] Additional "compliance" SUVs with electric drivetrains added to conventional model vehicles have been also been marketed, e.g., Toyota RAV4 EV.

[b] And as noted above, this problem would be greatly exacerbated under severe hot and cold weather conditions, which both reduce vehicle range and increase charging time.

employees. DOE's Workplace Charging Challenge had already attracted over 250 business partners as of January 2015, with over 5,000 charging stations installed.[100]

5.7 Barriers and the Policies, Regulations, and Programs That Address Them

There are a number of policies, regulations, and incentives to support increased penetration of EVs. Several of these are summarized broadly in Table 5.6, and Table 5.7 details the specific state-level incentives and policies that are active in each state.

Most states offer a range of incentives for PEV purchases and owners. Some of these might be direct financial incentives, augmenting the federal tax credit of up to $7,500 that is provided to purchasers of qualifying PEVs. There are also a variety of other incentives for PEV owners, such as permission to use high-occupancy vehicle (HOV) lanes at all times and reduced electricity rates for vehicle charging. In addition, 10 states[a] have adopted California's ZEV sales mandate, which requires that ZEVs account for a specified share of total vehicle production by large car manufacturers (including a 15% ZEV sales target by 2025). Manufacturers can sell various classes of ZEV credits to others who fall short of prescribed targets, similar to renewable electricity credits in the power sector. The market for such credits can be significant. For example, Tesla Motors generated $76.1 million in revenue from selling ZEV credits in the third quarter of 2014, which amounts to 8.2% of the company's total revenue that quarter.[101] Of course, as more models of PEVs are introduced and sold by more manufacturers, the value of these credits is likely to decrease, unless ZEV targets increase as well. Both the U.S. EPA Light Duty Vehicle Greenhouse Gas Emissions Standards and National Highway Traffic Safety Administration corporate average fuel economy (CAFE) standards provide incentives for the increased deployment of light-duty EVs. The federal emissions and fuel efficiency standards for medium- and heavy-duty vehicles also incentivize increased deployment of EVs.

[a] California, Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island, and Vermont.

Table 5.6. Policies, Regulations, and Programs in the Transportation Sector

Codes, Mandates and Target-Setting	• **The U.S. EPA LDV GHG Emissions Rule provides a credit multiplier for PEVs sold in model years 2017 through 2021. PEVs are currently awarded a zero GHG emissions score by EPA and high fuel economy levels by the National Highway Traffic Safety Administration.** • **The EPA Renewable Fuel Standard and California Low Carbon Fuel Standard both include credits for renewable electricity used to power PEVs.** • **Ten states currently have zero emission vehicle (ZEV) mandates, which require that ZEVs make up a certain fraction of all new vehicle sales.**	***Non-energy benefits, lack of private incentive for R&D, various others*** • **These policies are generally enacted to accelerate technology learning and economies of scale to ultimately reduce costs and promote long-term adoption.** • **Temporary GHG regulatory incentives slightly reduce near-term GHG savings in order to promote PEV technology that could yield large, future GHG savings.[102]**
Grants and Rebates	• Payments to consumers who purchase a PEV • The federal program currently offers up to $7,500 for light-duty vehicles (LDVs). • Multiple states have additional programs, typically $2,000 to $3,000 in additional incentives.	*First costs, non-energy benefits, materiality, information/awareness* • Rebates lower the incremental up-front cost of efficient technologies, serving as a proxy for non-priced social benefits of energy efficiency adoption.
RD&D for End-Use Technologies	• Major battery RD&D initiatives have been sponsored by DOE to (a) reduce costs of storage and (b) increase storage density. • Initiatives have been implemented to improve charging infrastructure and reduce charging time.	*Lack of private incentive for R&D, consumer risk aversion* • In general, RD&D is undersupplied absent policy intervention because its benefits cannot be fully appropriated by inventors (a "public goods" problem). • Many consumers have "range anxiety," and are thus hesitant to make the shift toward electric vehicles. High first costs are another contributing factor. • Similar issues exist for buses and public transit.
Public Infrastructure Investments	• Federal program and multiple states have programs focused on building charging infrastructure. • Federal, state, and local entities invest in rail and other public transporation infrastructure. • Some states have alternatively attempted to recoup infrastructure costs from PEVs that do not pay gasoline taxes through alternative measures (e.g., registration fees).	• Increased PEV penetration is heavily contingent on the availability of charging infrastructure. • More charging stations will help overcome "range anxiety." • High up-front capital investment is required to create supportive environment, tipping point effect. • With more PEVs on the road, per vehicle infrastructure cost will decrease. • High first infrastructure costs exist for light and heavy rail also.

Table 5.7. State Incentives for PEV Purchases and Owners[103]

Incentives	State
PEV Purchase Incentives: Tax Credits and Rebates (Including Low-Interest Loan)	California, Colorado, Connecticut, Delaware, District of Columbia, Kansas, Illinois, Maryland, Massachusetts, Nebraska, Oklahoma, Oregon, Pennsylvania, Rhode Island, South Carolina, Tennessee, Utah, Washington, West Virginia
Zero Emission Vehicle (ZEV) Mandates	California, Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island, Vermont
High-Occupancy Vehicle Lane Exemption	Arizona, California, Colorado, Florida, Georgia, Hawaii, Maryland, New Jersey, New York, North Carolina, Tennessee, Utah, Virginia
Lower Electric Rates for Residents with Separate Meter for PEV Charging	Alabama, Arizona, Georgia, Hawaii, Indiana, Kansas, Kentucky, Maryland, Michigan, Minnesota, Nevada, Virginia
Charging Equipment / Installation Incentive	Arizona, California, Colorado, Connecticut, Delaware, Georgia, Illinois, Indiana, Maryland, Massachusetts, Michigan, Missouri, New Hampshire, New Jersey, Oregon
Vehicle Inspection / Emission Testing Exemption	Arizona, Connecticut, Idaho, Illinois, Michigan, Missouri, Massachusetts, Nevada, North Carolina, Ohio, Rhode Island, Virginia, Washington
Parking Incentives	Arizona, Hawaii, Nevada
Sales Tax Exemption	Colorado, New Jersey, Virginia, Washington
Fuel Tax Exemption	Idaho, Wisconsin, Utah
Reduced License and/or Use Tax	Arizona
Reduced Registration Fee	Connecticut, District of Columbia, Illinois
Conversion Tax Credit	Montana, Nebraska, Louisiana
Vehicle-to-Grid Energy Credit	Delaware
Weight Limit Exemption	Colorado
Title Tax Exemption	District of Columbia
Reduced Toll Road Rates	New Jersey

As the market for PEVs is still relatively immature and most incentive programs are new, it is difficult to assess how effective programs have been in increasing PEV sales. However, a number of studies have attempted to analyze early results from these programs; selected high-level findings are as follows:

PEV adoption appears to be greatest when multiple actions are taken in parallel: PEV incentives have been offered through a variety of different mechanisms, for example, direct cost reductions, infrastructure investments, and non-monetary benefits to vehicle owners (e.g., HOV or parking access). Studies suggest that incentives are most successful at increasing PEV adoption when multiple incentives are offered simultaneously, especially when policies focus on both making vehicles more affordable and attractive and expanding charging infrastructure. Preliminary research indicates that both incentives and charging infrastructure availability are positively correlated with BEV registrations,[104] while other results show that that the top EV adoption cities tended to have some combination of more EV promotion action, greater charging infrastructure per capita, greater consumer incentives, and greater model availability.[105] Sierzchula also notes that both charging infrastructure and financial incentives were important to PEV adoption but neither alone ensured high adoption rates.[106]

Policies to reduce the high up-front cost of PEVs appear to promote early market growth: The high up-front purchase cost has long been considered to be a major barrier for market adoption of PEVs. It has been shown that tax rebates to defray the up-front purchase cost are one of the most effective ways of increasing consumer purchases of a PEV.[107] However, one study notes that tax credits are less effective than immediate rebates, as they must be claimed by the purchaser at a later date and are subject to some uncertainty as they depend on the purchasers' tax liability.[108]

Institutional support factors also appear to be effective in promoting market growth: Some institutional support factors, such as emissions testing exemptions, low-carbon fuel policies, and outreach actions to support general EV awareness, have also played an important role in PEV market adoption, as recognized by three studies from the International Council on Clean Transportation.[109] [110] [111] One additional study found that PEV Readiness Grants have had a strongly significant positive effect on PEV adoption rates, especially in states without incentives.[112]

Vehicle charging infrastructure is an important prerequisite for PEV adoption: Lutsey also identified gaps in promotion actions. First, public charging infrastructure availability has a significant impact on both PHEV and BEV purchases.[113] Even large financial incentives have limited positive effects on PEV adoption if there is a limited charging infrastructure and EV model availability. Such a pattern has also been observed in the European Union. For example, Denmark has large vehicle purchase incentives but limited charging infrastructure and limited PEV success. Similarly, New York City has adopted many vehicle purchase promotion actions and has high EV model availability, but has much less charging infrastructure than the other 24 cities studied. However, lack of state incentives could also contribute to the low market adoption rate in New York City. Future analyses should attempt to isolate the impacts of these possible contributing factors. Note that the quantity of public charging infrastructure may not be as important as ensuring that consumers have ready access to real-time data on the location and availability of charging infrastructure.

Several studies have reached contradictory conclusions: Contrary conclusions were reached by some studies even when their analyses were based on the same year of registration data. For example, HOV access was shown to not have a statistically significant effect on BEV purchases in one study using a logit model.[114] Another study that utilized stepwise regression models showed that HOV lane access is one of the most effective promotion actions for BEVs.[115] Two more studies, one using regression analysis[116] and one using surveys,[117] concluded that HOV lane access also encourages PHEV purchases. The contrary conclusions may be associated with the different variables used in each model, in addition to methodological differences.

Contrary conclusions were also found regarding whether purchase rebate or tax credits are a more effective tool for promoting PEV adoption. Coplon-Newfield found that an immediate rebate is more attractive to consumers than a year-end tax credit, based on the experiences in the northeast and mid-Atlantic states.[118] However, Clinton et al. concluded that tax credits are significantly positively correlated with BEV registrations while BEV rebates have a positive but not statistically significant impact.[119] Jin et al. concluded that subsidies (for both vehicles and infrastructure) are one of the most effective incentives based on step-wise regression analysis.[120] However, this study refers to both tax credits and rebates jointly as subsidies.

5.8 Outlook through 2040

As noted earlier, the U.S. transportation sector in 2016 uses virtually no electricity. Some 88% of transport electricity use is for transit, commuter, and intercity passenger rail.[121] In addition, there is a small but growing movement toward light personal EVs, including passenger cars, light trucks, motorcycles, and bicycles. Some transportation companies, such as FedEx and UPS, are experimenting with electric delivery vans for their shorter routes, and some bus transit companies, such as Foothill Transit in California, have begun to use electric buses.

Unless a substantial fraction of light personal vehicles (and small delivery vehicles) become electrified, transportation electricity use will likely continue to play a minor role in the U.S. electricity sector. However, there currently is a concerted effort by the federal government, a number of state governments, utilities, and non-governmental organizations to promote the electrification of transportation, especially for LDVs.

The future of electricity use in transportation will depend in large part on the following factors:

- Future growth of personal travel and freight transport, and its characteristics
- The relative costs of electric versus fossil-fuel powered transport, influenced strongly by world petroleum prices and battery costs and performance (and government subsidies for both technologies)
- Consumers' awareness of and reactions to new alternative transportation products and their willingness to pay an up-front premium for electrified vehicles, as well as business decisions about developing and promoting EVs and building a robust charging infrastructure
- State and federal government regulations (see Table 5.6 and Table 5.7) and fleet purchase decisions

5.8.1 Growth in Travel

Table 5.8. Historical Growth Factors in Vehicle Travel and Status Today [122]

Growth Factor	Reason for Disruption
Increased levels of participation in the labor force by women	Trend now essentially saturated
Increased access to vehicles—ratio of vehicles to potential drivers soared and number of zero-vehicle households dropped	Number of vehicles per person ≥ 16 years old is now nearly one, and the percentage of zero-vehicle households has dropped below 10%
Sharp drops in average passenger loads in personal vehicles, related to increased vehicle access	Halted and somewhat reversed
Increasing speeds on U.S. highways	Highway speeds have stabilized
Sharp drops in transit usage, with former users shifting to cars	Halted, with some recent growth in transit usage
Substantial migration from the inner core of cities to suburbs, with greater distances to access services	Halted and somewhat reversed

A recent paper on the prospects for future vehicle travel growth (Table 5.8) in the United States concludes that future growth rates will be well below pre-2007 rates.[123]

The EPSA Side Case projects total light-duty fleet VMT to increase by 1.1% per year from 2015 through 2040 for a 31% total increase, from 2,731 billion VMT in 2015 to 3,565 billion VMT in 2040.[124] Although low energy prices might increase VMT, they would also likely slow the electrification of travel by making conventional vehicles more attractive relative to PEVs. Alternatively, the implementation of new policies and incentives to support PEV adoption could increase electric VMT.

Changes in the distribution of personal vehicle travel (as well as changes in population patterns, especially urban versus suburban versus rural) will also affect prospects for LDV electrification. The rise of services like Uber and ZipCar, as well as shifts to autonomous vehicles, may further affect both travel patterns and volume and provide new markets for EVs. Analysis of such prospects is a topic for further research.

Changes in the magnitude and distribution of freight transport will also affect electrification prospects. In general, long-distance trucking and water shipping are unlikely to be electrified to any extent. Electrification of rail shipping seems unlikely without major public incentives, and air shipping (and air travel) will not be electrified for technical reasons. However, the growth in Internet shopping and the trend toward locating warehouses nearer to markets to facilitate rapid shipping will inevitably lead to growth in shipping via smaller vans and trucks over relatively short distances. This raises the *potential* to electrify a portion of freight transport, depending on the changing economics of electric versus fossil-based vehicles and progress in battery performance. The EPSA Side Case projects commercial light truck travel to grow by 1.7% per year and freight truck travel to grow by 1.5% per year, compared to LDV travel growth of only 1.1% per year.[125] Unfortunately, the EPSA-NEMS dataset does not allow for an analysis of changes in "small truck/short distance" travel.[a]

5.8.2 Relative Costs

Rail transit is primarily electric and will remain so. As such, the overall cost of building and maintain rail transit will affect its prospects for expansion, rather than its choice of energy source. The economics of rail transit look poor from a simple comparison of fare revenues and operating and capital costs of the systems. Fare payback is only 38% for the largest systems, generally worse for others.[126] The economics are much better if other savings (e.g., reduced traffic congestion, reduced parking requirements, fewer traffic accidents) are included, but the magnitude of these savings is controversial. A similar case can be made for bus transit, and large investments in both rail and bus systems have been difficult to obtain in recent decades. Major expansion of rail systems and investments in electric buses and charging infrastructure will require a shift in public sentiment as well as a renewed interest by the federal government in building transportation infrastructure.

The costs of plug-in personal vehicles must become more favorable if rapid electrification of the fleet can be realistically expected. This gap can also be overcome by allaying consumer range anxiety and increasing awareness of the value proposition presented by PEVs. As discussed in Section 5.3, battery costs are expected to drop sharply during the next decade through learning and economies of scale, and

[a] Delivery trucks comprise both commercial light trucks and a portion of freight trucks, which are not broken down in the AEO 2015 dataset. AEO data also do not provide information on the changing distribution of freight trip distance.

multiple efforts by governments and industry worldwide seek to reduce costs further as well as achieve major increases in battery performance and lifetime. There appears to be a reasonable chance—but not a certainty—that reductions in battery costs and improvements in performance will be sufficient by 2025 or 2030 to achieve cost parity of shorter-range (~100 miles) BEVs with conventional vehicles, while making both longer-range BEVs and PHEVs more attractive and cost-effective.

5.8.3 Business and Consumer Reactions

Although there is a great deal known about how markets respond to changes in the price and performance of conventional vehicles, EVs are a relatively new phenomenon with rapidly changing costs and characteristics, and current data about market response are relevant to "early adopters" rather than to the mainstream public. In general, it is expected that EVs will not take off until consumers become very familiar with the technology, believe that higher vehicle costs will be rapidly paid back by fuel savings within a few years, and perceive that enough public charging infrastructure has been built to allay range anxiety. A reduction in charging time for public chargers may also be necessary for those consumers who frequently rely on public charging infrastructure, and this may be technically challenging. Additional benefits recognized by the current PEV customer base—performance, quiet operation, convenient charging, local procurement, new technology, and environmental friendliness—must be clearly understood by the general buying public. Achieving a good understanding of how market actors behave toward PEVs probably requires several more years of tracking purchase and driving behavior, as well as expansion of the PEV market to mainstream consumers. (See Section 5.6 for a discussion of markets and market actors.)

Business reactions to electric transportation, particularly to light-duty PEVs, appear positive at this early stage of PEV development. Several companies have developed purpose-built BEVs and PHEVs that take account of both the special requirements as well as the potential advantages of battery-powered vehicles. Also, there has been a strong response to calls for building a public charging infrastructure as well as a workplace charging infrastructure, with hundreds of businesses signing on to DOE's Workplace Charging Challenge.

5.8.4 Government Regulations and Fleet Purchase Decisions

As noted above (Section 5.7), federal, state, and local governments have taken multiple actions to promote EVs, and their continuance and possible expansion will play an important role in whether or not PEVs gain significant market shares. A key decision point for the future is whether or not to extend federal tax credits for PEVs. Other key factors include:

- Support for expanding public charging infrastructure at all levels of government
- Local building codes, e.g., requirements that new homes either include charging circuits or at least be designed for easy installation of PEV chargers
- Continuation and possible expansion of non-monetary incentives, e.g., access to HOV lanes
    - A crucial factor will be the continued enforcement of ZEV requirements by California and nine other states. As shown later, if these ten states achieve their requirements, it has been estimated that PEVs will account for 6.5% of all LDV sales nationally by 2030. This will presumably help drive vehicle costs down through scale and learning effects.
    - Government fleets will also play a crucial role. According to a recent Executive Order, U.S. government fleets must incorporate 20% PEVs by 2020 and 50% by 2025.[127] Many state

and local fleets have initiated PEV purchases as well, although comprehensive data are not yet available.

5.8.5 Projections of Transportation Electricity Use

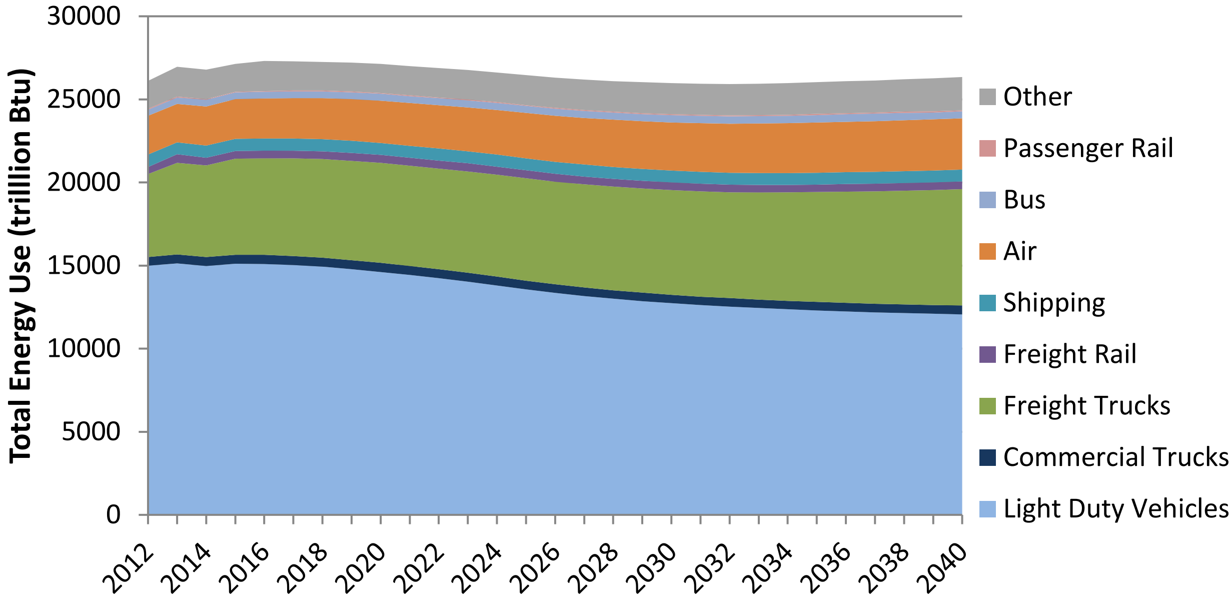
Projections of future sales of EVs vary widely, primarily because there are insufficient data for a robust understanding of the determinants of future sales, and some of the likely driving forces of such sales (e.g., future oil prices, future battery costs and performance, mainstream consumer reactions to the positive values, and the trade-offs associated with plug-in vehicles) are highly uncertain. Also, various projection models have major differences in structure and underlying assumptions, producing very different results even when input assumptions are the same.

EPSA Side Case

As of 2013, LDVs accounted for the majority (56%) of all energy consumption in the transportation sector.[128] While the EPSA Side Case projects their total consumption level to be about 20% lower in 2040, LDVs are still projected to account for nearly 46% of all transportation energy consumption.[129] Energy use by freight trucks is projected to grow by 27% between 2013 and 2040[130], with their total share of energy use in the transportation sector increasing from 20% to 27%.[131] Energy use by passenger rail is also expected to grow by about 26% through 2040.[132] However, the overall share of passenger rail in the whole transportation sector is projected to still be small—only 0.2%. Total delivered energy consumption for transportation is projected to decrease by about 2.5% by 2040 relative to 2013 levels, due largely to increasing vehicle efficiency.[133]

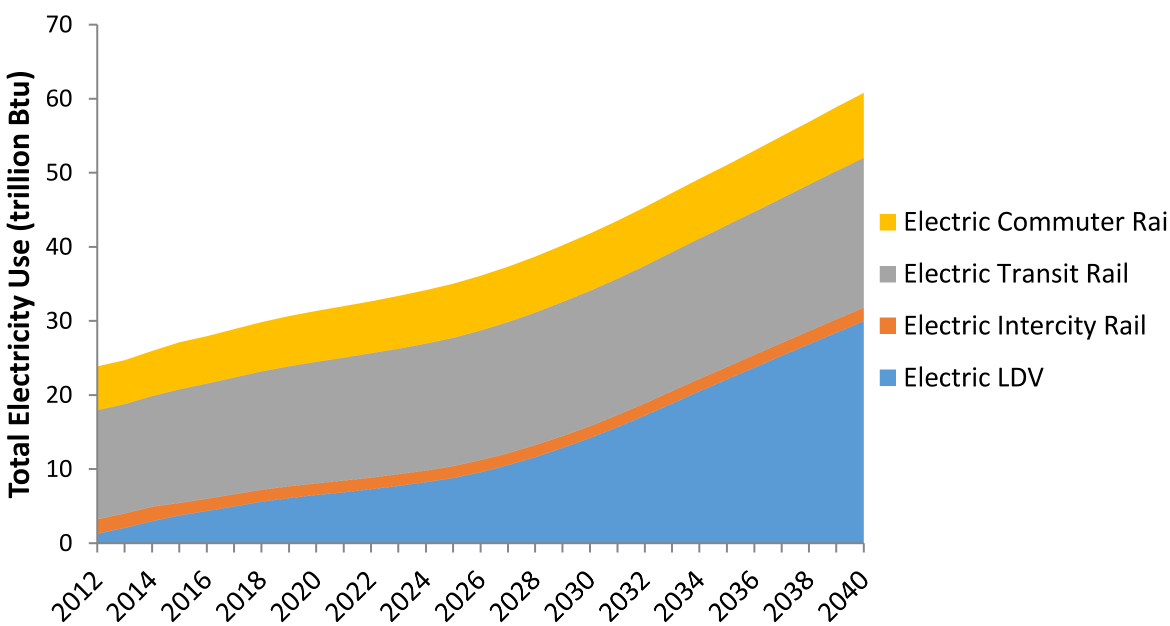
The current share of energy use for transportation that comes from electricity is very small— only 26 trillion Btu out of 26,790 trillion Btu total in 2014. The EPSA Side Case projects electricity use for transportation to increase by a factor of roughly 2.5 to 61 trillion Btu by 2040. However, this is still less than 1% of total projected energy consumption. Almost all of the increased electricity use in the sector is attributed to LDVs, as their electricity use is projected to grow tenfold, from 3 trillion Btu in 2014 to 30 trillion Btu in 2040. This estimate is based on projections of VMT and stock of PHEVs and BEVs. The EPSA Side Case projects that PEVs will account for 1.7% of all LDV sales in 2040 and 1.2% of the total LDV stock. The EPSA Side Case projects only marginal increases in electricity consumption for rail travel, and no electricity consumption from heavy-duty vehicles or buses in 2040. Figure 5.7 shows the EPSA Side Case projection for total transportation energy use by category through 2040 and Figure 5.8 shows the transportation electricity use for the same case. Note that these projections assume that there will no major policy changes to further promote the adoption of PEVs. Before using these projections to inform analysis or decision-makers the foundational assumptions should be reviewed to make sure they still reflect current conditions.

Figure 5.7. Projection of total primary energy use for transportation in the United States, all fuels[134]



Light-duty vehicles (LDVs) are responsible for the largest share of energy consumption in the transportation sector. However, this share is projected to decrease in the future. Freight trucks account for the second greatest share of energy consumption, and this share is projected to increase between 2014 and 2040.

Figure 5.8. Projection of total electricity use for transportation in the United States[135]



Electricity accounts for only a very small fraction of all energy consumption in the transportation sector. Under EPSA Side Case conditions, electricity use for transportation is projected to grow through 2040, primarily due to increased penetration of light-duty vehicles (LDVs).

Table 5.9 shows total energy consumption in 2014 and projected for 2040 for each electrified sector, with energy values in trillion Btu. As noted above, the EPSA Side Case projects that electricity will provide a near zero share of transportation energy in 2040, about 0.2%. Even with electrified transport's higher energy efficiency factored in, this case projects that electricity will power less than 1% of U.S. transport in 2040.

Table 5.9. Electricity Use and Total Energy Consumption in Transport Modes Using Electricity, 2014 and 2040 (in trillion Btu), from the EPSA Side Case[136]

Vehicle Type	2014 Electricity	2014 Energy	2040 Electricity	2040 Energy
Light-duty Vehicles	3	14,969	30	12,061
Intercity Rail	2	19	2	18
Transit Rail	15	15	20	20
Commuter Rail	6	17	9	26
Total Transport Consumption	26	26,790	61	26,341

The EPSA Side Case projects substantial growth in world oil prices, from about $56 per barrel in 2015 to $141 per barrel in 2040 (in real 2013 dollars).[137] Therefore, the projected continued dominance of oil in transportation cannot be explained by low oil prices. Instead, the primary factor holding back electrification of transport appears to be related to projected up-front capital costs for electric transportation, Table 5.10 shows a selected subset of the price projections for new LDVs that projected in the EPSA Side Case.

Table 5.10. Projected Prices for New Light-Duty Vehicles in 2016 and 2040, from the EPSA Side Case[138]

	Compact		Midsize	
Vehicle	2016 Cost ($)	2040 Cost ($)	2016 Cost ($)	2040 Cost ($)
Gasoline Car	20,753	23,395	25,270	27,638
Hybrid Electric Car	25,426	25,936	30,463	30,570
PHEV10 Car	30,693	28,985	36,613	34,383
PHEV40 Car	39,573	34,191	46,708	40,052
BEV100 Car	35,540	29,943	43,241	36,431
BEV200 Car	N/A	40,426	N/A	45,698

All prices are in 2013 dollars.

Based on EPSA Side Case assumptions, the payback periods compared to a 2040 conventional gasoline vehicle for a PHEV10, PHEV40, and BEV100 in 2040 are 27, 46, and 19 years, respectively, at a 0% discount rate. Even an HEV has a 13-year payback. [a] [139] And at the relatively high discount rates that consumers appear to use in their purchases of energy efficient products (20% is not unusual) the payback periods would look much worse to consumers. Aside from high assumed costs for HEVs and PEVs, these long payback periods reflect the EPSA Side Case assumptions (1) that tax credits or other subsidies will no longer be available in 2040, (2) that competing gasoline-powered cars will attain high

[a] Assumptions: gasoline price of $3.90/gallon; 12,000 miles traveled per year; $0.12/kWh electricity price.

fuel economy levels, thus reducing the fuel savings of PEVs, and (3) that there will be no additional policies affecting PEV penetration. All of these assumptions are subject to some debate, and in particular it seems quite likely that there will be a post-2025 extension of federal fuel economy standards, which might stimulate added emphasis by manufacturers on PEVs.

This is a rapidly evolving market and as a result the EPSA Side Case no longer accurately reflects the cost of vehicles that will soon be on the market.[a] For example, the dominant BEV in the current market, the midsize Nissan LEAF, with a 107-mile range, has an average manufacturer's suggested retail price (MSRP) of about $35,500.[b] The EPSA Side Case projects the price of a midsize BEV100 to be $43,241 in 2016. The new model year 2017 compact Chevrolet Volt, a PHEV with a 53-mile electric range to be released in 2016, has an average MSRP of about $35,400. The EPSA Side Case projects the price of a compact PHEV40 to have a higher price tag of $39,573 in 2016 despite its 25% shorter electric range. It is difficult to know for sure whether this superficial comparison is a fair one as there are multiple BEV and PHEV models on the market today (see Appendix Table 7.9), and therefore the comparison with a single model for each vehicle type may be inadequate.

Also, the EPSA Side Case aims to project vehicle prices for the long term, and these must reflect manufacturing costs. Automakers do not demand the same profit margin across their different nameplates,[c] and they may accept lower (or no) margins for models that have been introduced for regulatory reasons or to enhance the company's reputation as a technology leader. It is likely that automakers that are competing in multiple market segments will sell advanced-technology vehicles like PEVs with smaller profit margins factored into their sales price, and at times may accept a (temporary) loss to gain sales share. However, when sales grow, prices will have to reflect reasonable profit margins. This means that current MSRPs for PEVs may not reflect the actual costs of vehicles as accurately as might be hoped for modeling purposes.

The EPSA Side Case also projects that the other transport sectors—shipping, air travel, freight trucks, and buses—will not electrify, at least in any significant way. Some of these modes would be unlikely to electrify under any circumstances, including air travel, most shipping, and long-distance trucking (unless highways were underlain with electric wires, allowing continuous wireless power transmission). Other modes, especially package delivery trucks and transit buses, may become electrified with some combination of high oil prices and greatly reduced battery prices (and higher battery performance), but the Reference case does not make these assumptions.

EIA has presented preliminary Reference case estimates for the AEO 2016 to its Transportation Working Group.[140] These estimates incorporate the potential effects of the ZEV mandates of California and several other states and yield PEV sales estimates for future years that are much higher than those of the EPSA Side Case. In particular, projected BEV sales are about 550,000/year in 2040, compared to about 100,000/year for the AEO 2015, and projected PHEV sales are about 400,000/year versus about 180,000/year for the EPSA Side Case. Total PEV fleet stock in 2040 for the preliminary AEO 2016 projection is over 12 million vehicles compared to about 3.3 million for the AEO 2015; also, the preliminary version of the AEO 2016 projects that over a million fuel cell vehicles will be in the fleet by

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[a] EPSA, like EIA, uses manufacturer's suggested retail prices (MSRPs), without options. The MSRPs are a sales-weighted average of all nameplate models—e.g., Honda Accord, Ford Fusion—in each size class. The historical data that EIA collected uses a simple average MSRP across trim levels for each nameplate.

[b] This reflects the average MSRP for the two trim levels—SV and SL—of the LEAF that attain the 107-mile range; the S trim level attains only 87 miles.

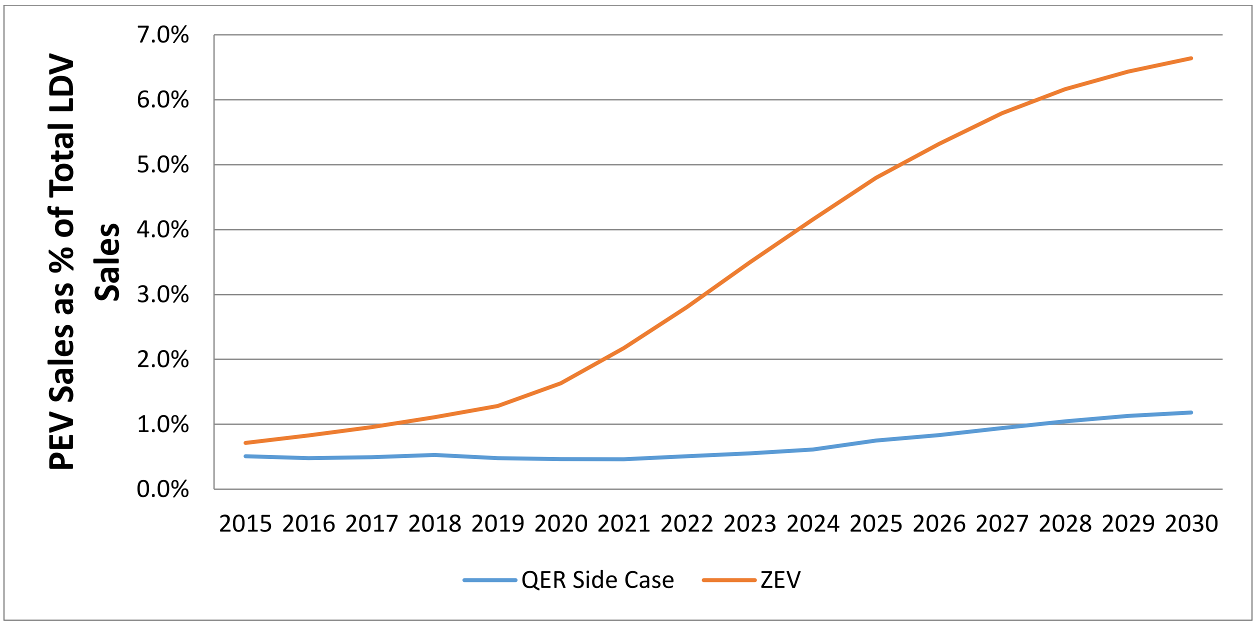
[c] Automakers make more money from their luxury models than from their mainstream entries, for example.

2040, versus about 60,000 in the AEO 2015. It is important to note, however, that even with these higher PEV penetrations, PEVs will remain a small component of the LDV fleet. In 2040, the preliminary AEO 2016 projected LDV fleet stock value at about 270 million vehicles, and therefore PEVs would make up about 4%–5% of the overall LDV fleet in 2040 at these higher estimates of PEV sales.

Additional PEV Sales Projections

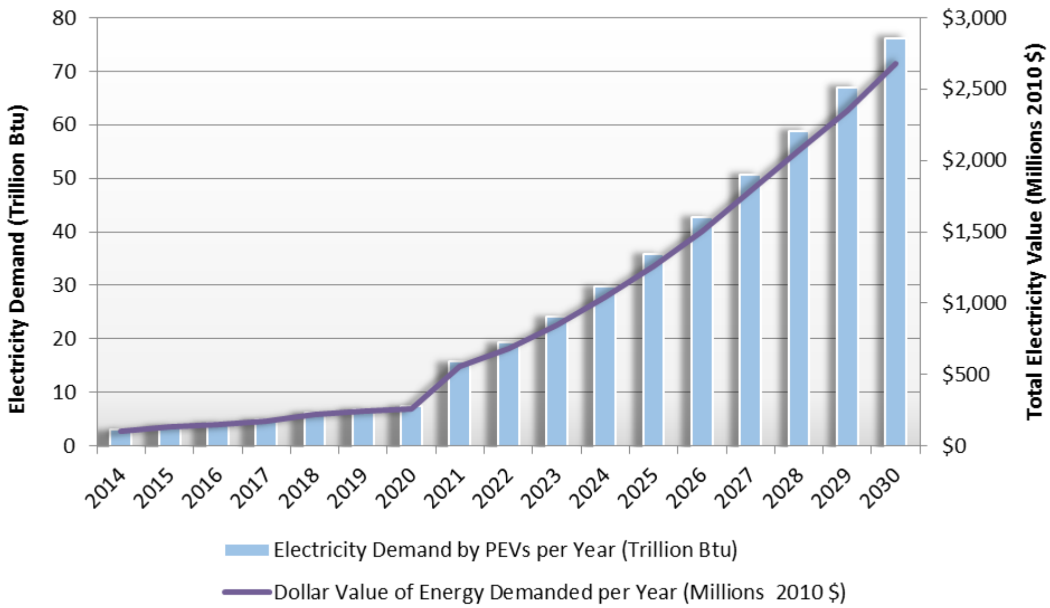
An economic impact analysis of e-mobility by Argonne National Laboratory estimated the electricity consumption of all PEVs on the road by 2030. This analysis assumes that all of the states that have adopted California-style ZEV sales requirements meet their stated goals and account for 70% of all PEV sales in the United States. As indicated in Figure 5.9, such a scenario would result in future PEV sales rates that are more than five times greater than those projected by the EPSA Side Case, reaching roughly 6.5% of all LDV sales in 2030 compared to the roughly 1.2% projected by the Side Case. Similarly, total electricity consumption by PEV is projected to be more than five times greater than EPSA Side Case projections—over 75 trillion Btu compared to roughly 14 trillion Btu (Figure 5.10). This scenario shares the same assumptions with respect to PEV efficiency (i.e., miles per kWh), range, utilization (i.e., miles per vehicle), and charging characteristics (e.g., duration, length, level, location) as the EPSA Side Case.

Figure 5.9. The U.S. PEV sales rate projected by an Argonne National Laboratory analysis of state Zero Emission Vehicle mandates[141]



The analysis projects that PEVs will account for 6.5% of all LDV sales in 2030, whereas the EPSA Side Case projects a PEV sales rate of 1.2%.

Figure 5.10. Projected electricity consumption by PEVs based on state ZEV mandates[142]



An Argonne National Laboratory analysis of state ZEV mandates projects total electricity consumption by PEVs to reach 75 trillion Btu in 2030. In contrast, the EPSA Side Case projects electricity consumption by PEVs to be roughly 14 trillion Btu in 2030.

Comparison of Five Vehicle Choice Models

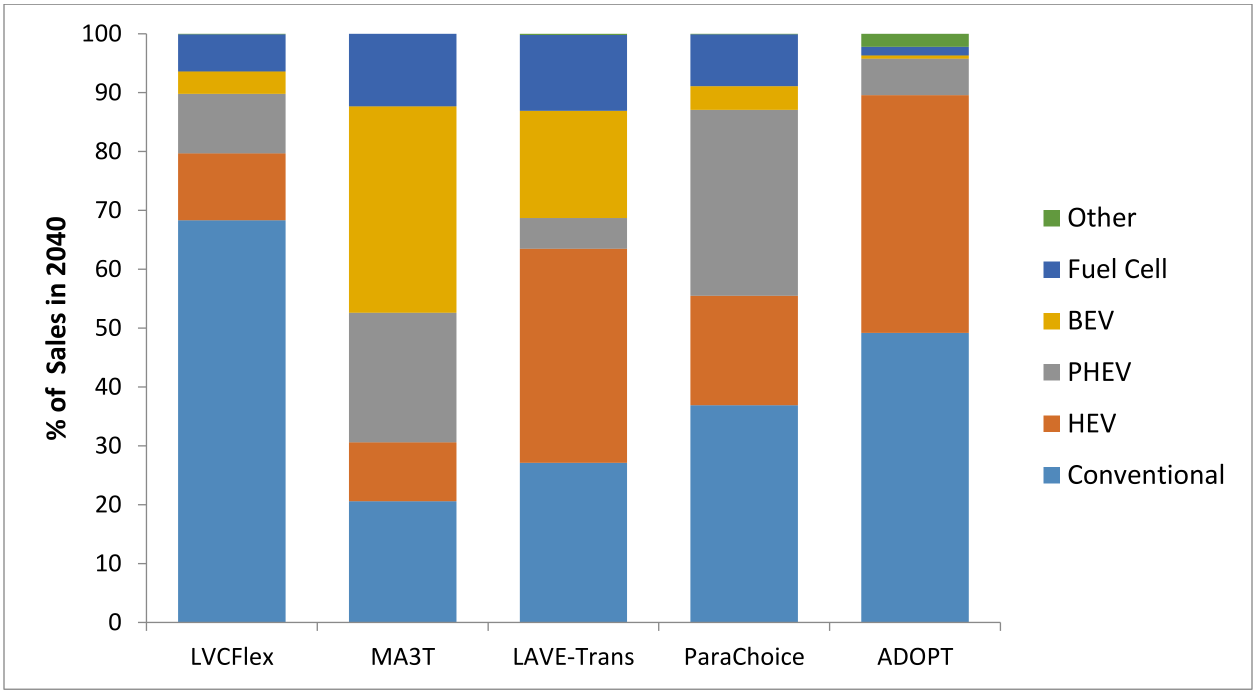
The market for future advanced-technology vehicles is very uncertain and impossible to predict credibly, due to uncertainties in future fuel prices, vehicle characteristics, automakers' marketing strategies, and consumer preferences. A number of projections of future vehicle sales have been made, but it is essential to appreciate that these are not predictions of the future, but only projections that represent possible futures. Large differences in projected outcomes result from differences in assumptions about future vehicle characteristics, consumer preferences, vehicle offerings, and other conditions, as well as differences in modeling methodologies. The usefulness of these projections is not in their predictive accuracy, but in revealing the uncertainty of future vehicle markets and important factors that can influence future market outcomes.

While the EPSA Side Case projects only minimal growth in electrified transportation through 2040, there are a number of vehicle choice models that arrive at dramatically different conclusions for LDVs.[143] These models are MA^{3}T (Oak Ridge National Laboratory, ORNL), LAVE-Trans (ORNL), LVCFLex (ORNL), ADOPT (National Renewable Energy Laboratory, NREL) and ParaChoice (Sandia National Laboratory, SNL). Figure 5.11 provides a comparison of the results from these five models under a No Program case.[a] The No Program case is a baseline based on simulations of future vehicles, and was developed by assuming that only incremental technology improvements would occur without support from DOE's VTO and Fuel Cell Technology Office (FCTO) programs. Parameters describing vehicle component performance, prices, and other attributes were estimated for 2010, 2015, 2020, 2025, 2030, and 2045 based on input from VTO and FCTO analysts and program managers and Argonne National Laboratory vehicle technology experts.

[a] The sets of input assumptions for the five models were designed to replicate the same scenario, so their outputs could be compared on an equal basis. However, the scenario examined was not equivalent to the AEO 2015 Reference case.

The model results show a wide disparity in projected PHEV and BEV sales rates in 2040. On one end of the spectrum, the ADOPT model projects a 6.2% BEV sales rate in 2040, with growth instead primarily occurring for HEVs. On the other end, the MA^{3}T model projects a 57.1% sales rate for PEVs and a further 12.3% sales rate for fuel cell vehicles, with only 20.6% of sales maintained by conventional vehicles. This illustrates the significant level of uncertainty in the potential growth of electrified transportation in the United States over the coming decades. Even the most conservative of these vehicle choice models (ADOPT) predicts PEV sales rates more than five times greater than those projected in the EPSA Side Case, while the most optimistic of these models (MA^{3}T) predicts sales rates almost 50 times greater.

Figure 5.11. Comparison of projected 2040 vehicle distribution by vehicle type, as determined by five vehicle choice models[144]



Vehicle choice models vary significantly in their projections of future alternative vehicle sales rates. The LVCFlex model projects that conventional cars will account for nearly 70% of sales in 2040, while the MA^{3}T model projects that alternative vehicles will account for nearly 70% of LDV sales, including 57% from PEVs.

Most of the growth potential for electrified transportation in the United States is in the market for LDVs, and to a lesser extent, medium-duty delivery vehicles and transit buses. Growth rates will also depend significantly on the extent of infrastructure investments, cost reductions for batteries and other electric drivetrain components, battery storage densities, and potentially, technology improvements that have not yet been identified. The significant variation in these projections makes it clear that there is far too much uncertainty in this growing and changing market to project transportation electricity use over the next 30 years with any reasonable level of reliability.

5.8.6 Outlook Conclusions

LDVs currently account for more than 50% of all U.S. transportation-related energy consumption and represent by far the largest area for potential growth in electrified transportation. It is difficult to project the future market adoption rate of electric LDVs due to uncertainties regarding changing consumer preferences, technological improvements, future technology costs, future oil prices, economic growth, and policy changes.

The EPSA Side Case projects very modest growth in PEVs through 2040. However, this projection appears to be overly pessimistic given the PEV cost assumptions and projections that are used in this analysis. The EPSA Side Case also explicitly does not consider any additional potential policy changes that could support PEV adoption. Specifically, if the 10 states that have adopted voluntary ZEV mandates achieve their goals, PEV sales rates could reach 4.5% by 2030 (not accounting for any growth in the remaining states) or as high as 6.5% (if moderate growth is achieved in the remaining states).[145] These trends are also indicated by the preliminary AEO 2016 results that consider the impacts of ZEV mandates. Alternatively, some vehicle choice models project that cost reductions and technological advancements could lead to PEV sales rates as high as 57% by 2040. Any such projections are dependent on a variety of uncertain parameter assumptions and therefore should be considered in the proper context. Such wide variation in projected PEV sales rates among projections that utilize different methodologies and assumptions underscores the inherent uncertainty in any such projections. It could therefore be concluded that any baseline projection of transport electrification may be only somewhat better than an educated guess.

The transition toward electrified transportation also represents a fundamental shift for consumers who will have to adapt to a new fueling paradigm. It is therefore possible that some sort of tipping point effect will be realized in the event that PEVs reach a particular price point or level of public acceptance. In this case, the steady adoption rates that are currently being experienced could suddenly give way to a period of rapid adoption as consumers make the transition toward the EV paradigm en masse. In this context, it is important to remember that PEVs have only been available to mass market consumers for five years, and it is therefore difficult to establish precedent for the future based upon the limited experiences to date. The relatively modest present share of PEVs, roughly 0.1% of the current LDV stock, by no means restricts potential future adoption.

In other sectors, the negligible growth projections for commercial light trucks and freight trucks in the EPSA Side Case are also likely overly pessimistic due to likely battery improvements, as well as shifts in the delivery model for consumer goods toward online shopping and home delivery (using commercial light trucks and smaller types of freight trucks traveling relatively short distances). The negligible growth projections in the Reference case for electrified passenger rail do not appear to account for potential consumption from the California high-speed rail system that is currently under development. However, unless there is a large paradigm shift in U.S. consumer preference from highway and air travel to rail travel, any growth in electricity consumption from passenger rail will remain relatively small when compared to the potential from electrified LDVs. The projection of essentially zero penetration in bus transit is impossible to assess; although a few transit companies have placed some electric buses in service and longer-range electric buses are now available, it is too early in the development process to make a robust projection. As with passenger rail, any growth in electricity consumption will be small because of bus transit’s small share of passenger transport. The projection of zero progress in electrifying freight rail appears to be in line with the industry's lack of interest and major capital commitments. Similarly, the projection of essentially zero growth in electrification of other modes (e.g., air travel, shipping) appears realistic.

5.9 Research Gaps

Following are key research questions and research gaps related to electricity consumption in the transportation sector:

1. What would be the effect of widespread electrification of transportation on the electric grid? How would these effects interact with increased penetration of renewable resources? If electricity use in transportation grows, the magnitude, controllability, and timing of the increased electricity demand will determine its effect on power systems. Geographical concentration of PEVs may strain local transformers, for example. If recharging can be spread over time periods of lower demand, the demand for new electric power production capacity could be minimized and grid economics could be improved. Increased electric transportation loads could also offset projected load reductions from energy efficiency improvements, thereby supporting asset utilization and investments in grid modernization. If PEV batteries can provide storage and balancing services to the grid (vehicle grid integration), variable renewable energy resources such as wind and solar could benefit, and PEV batteries that have been retired from vehicle service might serve as grid storage batteries as a second life. Finally, if electricity use in transportation grows, the achieved emissions reductions will vary regionally based on the current and future fuel mix of electricity generation. Increased analysis and modeling is needed to better understand the net emission impacts, both at a regional and national level.
2. What are the principal determinants of PEV penetration? How can we reliably project PEV penetration? Our current understanding of the factors that will influence future PEV sales is based on our understanding of consumer purchase behavior for conventional vehicles, economic theory, and data from only a few years of actual purchase behavior for PEVs. An important limitation of actual PEV purchase behavior is that it largely reflects the behavior of early adopters, a relatively small portion of potential buyers of new vehicles with a unique set of consumer behaviors and relatively limited market offerings. Continued monitoring and analysis of vehicle sales behavior will be necessary to gain an understanding of mainstream consumers' purchase behavior toward plug-in vehicles, and how they might respond to increasing availability of more affordable PEV models, as well as potential sustained reductions in gasoline prices. We need to understand the value either perceived or real that will cause a willingness to implement a paradigm change from ICE to electricity. We further need to recognize the long time period required to achieve prior significant paradigm changes and manage accordingly.
3. How will changing patterns of personal vehicle travel affect the prospects for PEV penetration? VMT growth is slowing, and there has recently been substantial movement of young professionals to urban areas. Furthermore, fewer young consumers are purchasing personal vehicles. Instead they are using ride sharing and services such as Uber, which could transition toward PEVs themselves. In addition, autonomous vehicles also hold potential to reduce net energy consumption and emissions if certain efficiency improvements, such as trip efficiency (i.e., lower congestion), vehicle "lightweighting," and vehicle-to-vehicle communications are not offset by increases in total travel demand. However, it is unclear if this will be a lasting trend and, if so, the extent to which it may affect prospects for PEV and other new car sales.
4. What business models will work for public charging infrastructure? A substantial public charging infrastructure may have to be in place before large numbers of consumers will purchase BEVs for anything other than purely local service. This implies that public chargers may be underutilized for some time. As batteries improve and vehicle range increases, home recharging will cover an increasing percentage of total trips, but public stations will still be needed for longer trips. Also,

longer trips that require public recharging may have severe peaking issues—e.g., holiday weekends. Further, a combination of heavy traffic and severe heat or cold could greatly exacerbate public charging accessibility issues, since temperature extremes both decrease vehicle range (demanding more frequent recharging) and increase charging time.

5. What policies can be adopted to encourage and shape transport electrification? Evaluating potential electrification policies requires the same kind of knowledge that projecting PEV sales penetration does—a deep understanding of consumer and business behavior. Such evaluation will require nuanced data mining of information from consumer and business behavior regarding other technologies. It will also require careful examination of evolving data from the current generation of EVs and new electrification business ventures and the acknowledgement that business models for vehicle manufacturers and dealerships might evolve to better support PEV adoption; for example, car companies might package charging control and even home charging and public charging services into the sale. Additionally, it will be important to understand how transport electrification may be affected by the adoption of potential new national scale climate policies.
6. What effect will a rising share of PEVs have on the resilience of the transportation system? Although diversifying energy sources in the transport system may superficially appear to increase resilience, electricity has a number of unique characteristics that may complicate this assessment. In particular, in a future where transport has been extensively electrified it may become difficult to move transportation fuel (electricity) into an area where the electric grid has been disrupted. It is, however, also not clear if the impact of such disruptions would be greater or smaller than those from potential similar disruptions of gasoline supply chains and natural gas distribution systems.
7. What is the full value of education and outreach efforts to promote increased consumer awareness of PEVs? How can education and outreach programs be designed to clearly communicate the value proposition of EVs to consumers and their uptake in the market? What are the various programs that have been implemented to date? Which approaches have been successful, and which have not? What lessons can be learned from approaches to increase market adoption of similar products in sectors, e.g., energy efficient appliances?

Transportation Appendix

Table 7.9. Efficiency Data for the Most Recent Models of Mass-Market PEVs[146]

Manufacturer	Model	Type	All-Electric Range (miles)	Combined Fuel Economy—Charge Depleting[a] (MPG_{ge})	Combined Fuel Economy—Charge Sustaining (MPG)
BMW	Active E	BEV	94	102	
BMW	i3	BEV	81	124	
		PHEV	72	117	39
BMW	i8	PHEV	15	76	28
Smart USA	Smart ED	BEV	68	107	
Chevrolet	Volt	PHEV	38	98	37
Chevrolet	Spark	BEV	82	119	
Ford	Focus	BEV	76	105	
Ford	C-Max Energi	PHEV	21	88	38
Ford	Fusion Energi	PHEV	21	88	38
Honda	Accord	PHEV	13	115	46
Honda	Fit EV	BEV	82	118	
Mitsubishi	I EV	BEV	62	112	
Mercedes	B-Class	BEV	87	84	
Nissan	LEAF	BEV	75	114	
Toyota	Prius PHEV	PHEV	11	95	50
Toyota	RAV4 EV	BEV	103	76	
Tesla	Model S (60 kWh battery)	BEV	208	95	
Tesla	Model S (90 kWh battery)	BEV	265	89	
Fiat	500E	BEV	87	116	
Porsche	Panamera S E-Hybrid	PHEV	16	50	22
Cadillac	ELR	PHEV	37	82	33
Volkswagen	e-Golf	BEV	83	116	
Kia	Soul EV	BEV	93	105	

MPG: miles per gallon, MPG_{ge}: miles per gallon of gasoline equivalent.[b]

[a] *Charge depleting* means that the battery is providing most or all of the energy, and thus is being depleted; *charge sustaining* means that the PHEV is operating more like an HEV, with battery charge varying over a narrow range and most vehicle energy being provided by gasoline (or other conventional fuel).

[b] MPG_{ge} is a metric used by EPA to compare the fuel efficiency of conventional and alternative vehicles. The calculation assumes 33.7 kWh of electricity is equal to one gallon of gasoline.

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